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A Clear Exposition of the Principles Governing the Action of Storage Batteries. Detailed Instructions Regarding Their Construction, Care and Maintenance

By

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ILLUSTRATED

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INTRODUCTION

An electro-chemical generator, or electric cell as it is usually called, is a device for the conversion of the potential energy of chemical separation into the energy of an electric current.

If a plate of zinc be immersed in dilute sulphuric acid, chemical action occurs, the zinc is dissolved, forming sulphate of zinc, which remains in solution, and hydrogen is liberated and escapes. This is a case of simple chemical action, and the energy given out appears principally in the form of heat. If the displacement of the hydrogen by the zinc occurs under somewhat less simple conditions, a greater part of the energy developed may be made to appear in the form of an electric current. Thus, if a plate of zinc and one of copper be placed in dilute acid, care being taken that those parts immersed in the solution do not touch, and if the outer ends be joined by an electric conductor, it will be found that an electric current is developed which appears to flow from the copper to the zinc plate. Such an arrangement constitutes a simple voltaic cell.

Voltaic electric cells may be divided into two distinct types—viz. Primary and Secondary. In a primary cell the electrical energy is developed by the direct chemical decomposition of the excitant or electrolyte, and of one or

both of its elements, the magnitude and rate of such electrical development being chiefly dependent upon the chemical activity of the materials employed. A secondary, storage, or accumulator cell is the name given to that particular class of apparatus which, although quite inert in itself, yet, on the passage of an electric current through it, certain chemical changes are induced which render it capable of receiving, retaining, and redeveloping a certain amount of electrical energy, the ratio between that amount of energy put in and returned being dependent upon the chemical nature of the materials employed and the mechanical construction of the cell.

In spite of our lack of knowledge of the precise nature of the chemical changes which occur in lead sulphuric-acid cells, enough is now known to enable those concerned in their commercial manufacture to construct cells of any capacity, and capable of giving any rate of discharge. It is now usual to speak of storage cells as being of so many ampere-hours capacity per pound of plates, or per pound of complete cell.

Storage Batteries

Lead storage cells fall naturally into two classes—**viz.** those in which the active material is formed from the substance of the element itself either by direct chemical or electro-chemical action, and those in which the chemical formation is accelerated by the application of some easily-reducible compound of lead. Elements of the former type are usually called "Planté," and those of the latter "Faure" or "pasted," Messrs. Planté and Faure being the respective inventors. This arrangement, however, does not hold so good now as formerly, the two types having in a measure blended. Quite a number of storage cells have recently been introduced in which neither lead nor salts of lead is used in their construction. Under these circumstances it will, perhaps, be advisable to divide the subject into two sections. First, what are generally known as "stationary cells," or cells commonly used for storing electrical energy in central supply stations, for tramway work, and for ordinary electric lighting. Second, "semi-portable" and "portable cells," or those used for propelling electric launches, tram-cars, motor-cars, and similar electrically-driven vehicles, also still smaller types of cells now commonly used for actuating induction coils, for X-ray, and

wireless telegraphic work, and also for driving very small motor and electric hand-lamps.

STATIONARY CELLS

As previously stated, the exact nature of the chemical changes in a secondary lead-sulphuric-acid lead-peroxide cell is not yet established; but it has been conclusively shown by Dr. Gladstone and Prof. Tribe that sulphate of lead ($Pb\,SO_4$) enters largely into the composition of the active material on both elements in a discharged cell. Analysis has shown that the surfaces of the elements in a newly and fully-charged Planté cell consist of nearly pure peroxide of lead ($Pb\,O_2$) and spongy metallic lead (Pb) respectively on the positive and negative plates.

During the discharge, or if the cell be allowed to remain at rest, the sulphuric acid (H_2SO_4) in the solution enters into combination with the peroxide and spongy lead, and partially converts it into sulphate. The acid being continually abstracted from the electrolyte as the discharge proceeds, the density of the solution becomes less. In the charging operation this action is reversed, as the reducible sulphates of lead which have been formed are apparently decomposed, the acid being reinstated in the liquid, and therefore causing an increase in its density. This peculiar alteration in the nature of the acid solution, first noticed by Sir E. Frankland, enables us to ascertain at any moment both the state of charge and the general condition

of a cell, by simply finding its density or specific gravity by means of a suitable instrument.

It is well known that pure metallic zinc will not decompose water, even at such a high temperature as 100° Centigrade. Dr. Gladstone and Prof. Tribe, in their admirable researches on this subject, have shown that zinc, on which copper has been deposited in a spongy condition, was capable of splitting up the molecules of water, even at ordinary temperatures, oxide of zinc being formed and hydrogen liberated. If placed in a solution of sulphuric acid and water it started a very violent chemical action, sulphate of zinc and hydrogen being the result. They termed the two metals thus conjoined a *copper-zinc couple,* and they found that this agent was capable of bringing about other chemical changes which neither metal alone could effect. Users of primary batteries, and those conversant with electrolytic action, will at once understand the nature of this agent, and will readily recognize in its effects only an intensified form of that troublesome complaint with which we are so familiar, and which is usually known by electricians under the name of "local action."

In the Planté form of secondary cell the positive plate is a sheet of lead, upon which finely-divided peroxide of lead is distributed. The difference of potential developed by lead and lead peroxide when immersed in dilute sulphuric acid is as nearly as may be 2 volts, while that developed by zinc and copper in the same liquid is about 0.7 of a volt. Messrs. Gladstone and Tribe were induced to

think that the elements in a Planté cell acted very much in the same way as their copper-zinc couple, and by a series of experiments it was found to be so. They found that the lead-peroxide couple decomposed the sulphuric acid with the production of sulphate of lead. The destruction of the peroxide of lead by this action means so much diminution of the available amount of electrical energy. In the early stages of "formation," and when the peroxide of lead on the metal is very thin and small in quantity, its transformation into the white sulphate goes on very rapidly, and is frequently perceptible to the eye; but when the thickness of the coating is increased the time required for the conversion is naturally too long for this kind of observation. During each period of repose which is recommended by Planté the peroxide on the lead plate is completely, or almost completely, destroyed by local action, with the formation of a proportionate amount of lead sulphate. In the next stage, when the current is reversed, the lead sulphate is reduced by the nascent hydrogen which is liberated by the electrolytic action, and the amount of finely-divided lead capable of being peroxidized is largely increased.

From their observations it becomes evident that a lead-peroxide plate gradually loses its electrical energy by local action, the rate of such loss being varied according to the circumstances of its preparation, and the general condition of the cell. When elements are employed which have an extensive metallic surface, with but a thin coating of

peroxide, the relative amount of local action must necessarily be large in proportion to the amount of active material present, and therefore the cell will quickly lose its charge.

De Kabath Accumulator.—Many early experimenters with the Planté type of element devoted much attention to

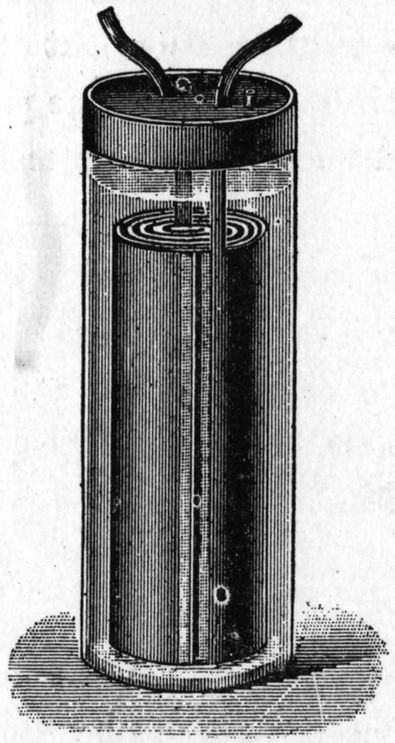

FIG. 1—PLANTE CELL

methods of obtaining the maximum amount of active surface with a minimum amount of weight of lead. Among the earliest of these was M. de Kabath. His form of element consisted of a thin perforated-lead chamber filled with a large number of lead strips.

To still further increase the exposed surface, and to allow of a more thorough circulation of the solution, each alter-

nate strip was fluted or crimped. The commercial pattern was prepared as follows:—

A number of thin lead strips, .39″ wide, 19.7″ long, and 1/25″ thick, were passed between fluted rollers which were grooved in such a way that their length was reduced to 14″. Lengths of the same thickness of lead were prepared. A perforated chamber, 3.4″ wide, was then made, and into this receptacle were packed about 180 or 190 of these strips, alternately one grooved and one plain. A perforated lead cover soldered on them completes the element. The

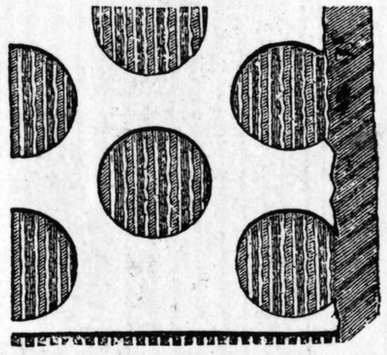

FIG. 2.—KABATH'S PLATE

complete plate measured 15″ in length, 3.54″ in width, and about .4″ in thickness. Twelve of these elements were placed in one cell. The formation was effected slowly, and in such a manner that the peroxide may adhere as firmly as possible. The process was maintained for some days, the direction of the current being occasionally reversed. The electrolyte was composed of distilled water to which was added one-tenth, by bulk, of pure sulphuric acid.

With a view to finding out the amount of surface to be obtained by rolling a given weight of lead, De Kabath

found by actual trial that 2.2 lbs. of lead rolled out 1/25″ thick exposed an active surface of 279 square inches.

Reynier's Cell.—The late Emile Reynier made many attempts to improve on the Planté cell. One of these

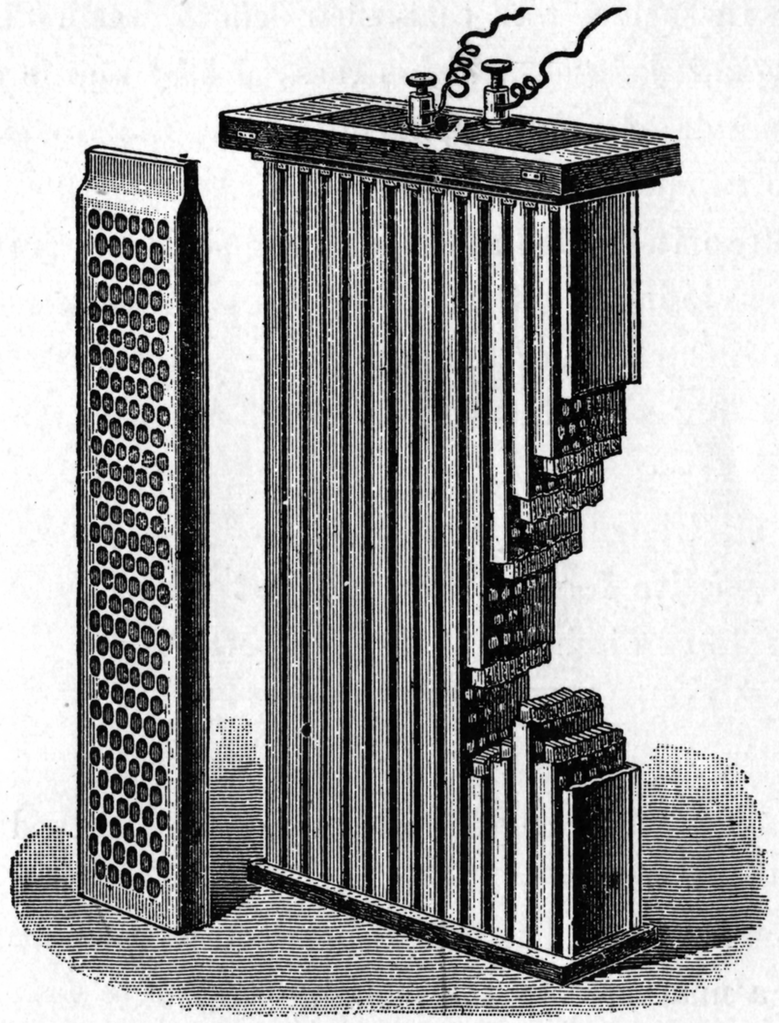

FIG. 3.—KABATH'S ELEMENT

consisted of a thin sheet of lead folded up zigzag fashion, and then enclosed in a stout cast-lead frame. During its formation the interior portions of the positive plate increased considerably in dimensions, but meeting with opposition from the rigid sides it did not warp up or bend,

but merely tended to close in upon itself. To decrease weight, and to still retain its mechanical strength, he ultimately substituted light steel frames which he coated with lead or some lead alloy. A still further improved form was what Reynier called his "elastic" cell. In constructing this he separated his electrodes by means of thin porous sheets of silica. Each cell contained one positive and two negative plates, and four sheets of the prepared silica. The two outer sheets of the insulator were corrugated so as to increase the space available for the electrolyte.

As an illustration of the capabilities of this form of cell, the following particulars of a 15-cell battery were given by Reynier:—

Total electromotive force, 32 volts.
Electromotive force at terminals, 28 volts.
Safe rate of discharge, 3 to 6 amperes.
Average available energy, 150 watts.
Capacity, 30 ampere-hours.
Work (available), 740 watt-hours.
Total weight of battery, 110 pounds.

D. P. Cells.—In this form of cell, known as the D. P. Accumulator the elements consist of a large number of narrow strips of lead built up one above another. Sometimes the narrow lead strips are obliquely corrugated to prevent the surfaces coming into contact. The plates are formed by the Dujardin process, which consists in immersing them in a solution composed of 2.2 lbs. of an alkaline nitrate, 4.4 lbs. of sulphuric acid, and 220 lbs. of water.

To regenerate the deoxidized nitric acid, air is forced into the bath during the forming operation.

The Rooney High-Discharge Cell, which is an American production, is very similar to the D. P. as regards mechanical construction. In this cell corrugated strips of lead are alternated with straight strips. These strips are lead-burned to a strong lead conductor, the whole being connected to a lead frame.

The positive elements are enclosed in a perforated hard rubber, or celluloid chamber. The forming process is accomplished in a nitrate solution.

The "Blot" Accumulator.—The Blot elements somewhat resemble those of the D. P. and Rooney make. Each element is made up of longitudinal coils of lead strip. The coils consist of alternately embossed and corrugated strips, so that the electrolytic is free to reach the whole of the lead surfaces. The thickness of the strips and the length of the coils is regulated according to the desired capacity of the finished cell. The coils are disposed vertically, their top end being burned to a stout lead conductor. By this arrangement the various sections of the plate are free to expand, so that warping and buckling are said not to occur.

The Lamina Plate.—These elements are made up of a series of perforated and corrugated lead strips. The method of making these plates is somewhat as follows:—Lead is received in the form of rolls of 8 to 10 inches wide, and of varying thickness of from 1/64 to 1/32 inch. The

lead is first perforated, and is afterwards corrugated by a suitable machine. After being treated in this way the lead is cut up into strips of the desired size. These strips when built up are encased by a sheet of perforated lead, held in position by leaden rivets, and lead-burned at the top and bottom.

The "Tudor" Accumulators.—The positive plates in this cell, which are perhaps its most distinctive feature, are lead plates of large surface, and formed on the original Planté method. The positive plates of all the different types made are similar in construction, and only differ in

FIG. 4.—TUDOR POSITIVE PLATE

their dimensions. The plates are cast in one piece with a large number of thin vertical ribs strengthened at intervals by horizontal ribs. The moulds in which the plates are cast are in two halves, each corresponding to one side of

the plate, and consisting of a rectangular cast-iron frame, in which are held a number of gun-metal racks, .6″ wide, cut with very fine teeth. A very small space is left between each rack, corresponding to a horizontal rib on the plate; at intervals of about 4.8″ a tooth is cut away on each rack so as to give an extra strong vertical rib at those points.

The thickness of the positive plates in all types of the Tudor cell is the same, viz. ½ inch, and the developed surface for electrolytic formation is ten times that of a smooth plate of the same superficial area.

The desired thickness of peroxide of lead on the positive plate is produced first by alternately charging the cells and then leaving them at rest on open circuit, and afterwards by alternately charging them at frequent intervals throughout the day, the discharge becoming greater as the state of formation proceeds. Finally, the cells are charged and discharged under ordinary conditions, until they attain nearly the normal capacity.

The negative plates are of the pasted grid pattern, and after being filled and dried, the majority of negative plates are sent out without any further preparation. It has been found that the active material of the negative plates, when formed, oxidizes and sulphates so readily, that the time required for reducing them after erection is scarcely lessened by a previous reduction of the litharge at the works.

The method of mounting the Tudor cell is the same in principle for all types of cells made. The plates are suspended above the level of the liquid by their lugs, from

the sides of the containing-box when it is made of glass, or from glass sheet when lead-lined wood boxes are used. In the small cells a free space of 4 inches, and in the large 8 inches, is left beneath the plates for the accumulation of deposit, so that this deposit cannot form internal short

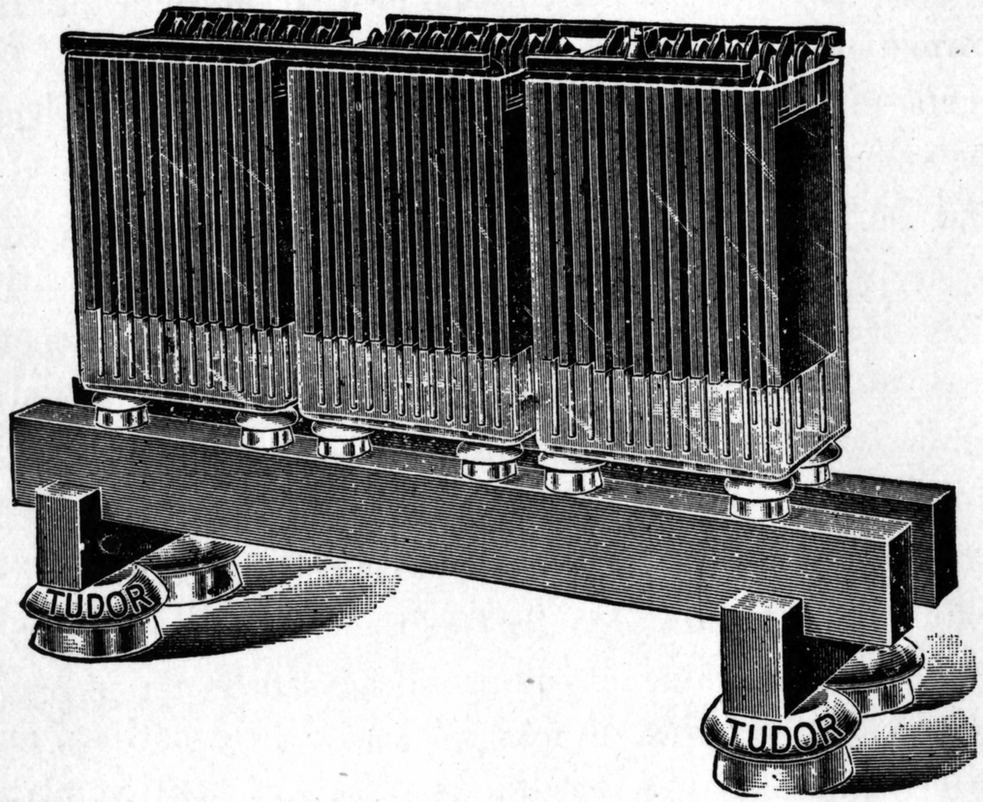

FIG. 5.—TUDOR ELEMENTS IN GLASS BOXES

circuits. The plates are free to expand in all directions. Each pair of plates is separated by two or more glass-flanged tubes ½ inch in diameter, held upright by guiding pieces cast on the lugs of the negative plates.

The plates are lead-burnt on to the connecting bars, as shown in Fig. 5, which illustrates some of the ordinary

lighting cells mounted in glass boxes. In the larger cells the connecting bars are common to the positive pole of one cell and the negative pole of the next one.

Faure, appreciating the many inconveniences and great loss of time involved in producing plates by Planté's electrolytic method, conceived the idea of accelerating the formation by applying a layer of oxide of lead to the surface of lead plates, and then converting this oxide into active material by the action of an electric current. To this end he coated his plates with minium or ordinary red oxide of lead, made into an adherent paste by the addition of water or acidulated water. When sufficiently hardened, these plates were placed in a cell containing dilute sulphuric acid, and then subjected to electrolytic action. To prevent the salts falling away from their support, he interposed between the plates porous felt or cloth. Faure found that the oxide on the positive plate was converted largely into peroxide of lead, while the salt on the negative was reduced to chemically porous lead.

The following data of one of these cells will doubtless be of interest: The cell was made up of sixteen flat plates of lead 17 inches long by 12½ inches wide. The positive electrodes were .08″ thick and the negatives .04″. The total amount of lead oxide pasted upon the plates weighed about 50 lbs. To prevent disintegration of the oxide, the plates were covered up first with parchment paper, and then with stout felt. The total weight of this combination, including the containing cell, was about 135 lbs. According

to some tests made with this cell, the following results were obtained:—

Duration of Discharge	Rate of Discharge	Total Current Output
8 hours	22 amperes	176 ampere-hours
12 hours	21 amperes	250 ampere-hours
13 hours	20 amperes	280 ampere-hours
14 hours	19 amperes	299 ampere-hours

This type of cell is known as the Faure "pasted" cell, but owing to defects which speedily developed themselves, it has never come into commercial use to any great extent.

The Faure Cell Theoretically Considered.—It is not within the province of this article to consider to any great extent the chemical actions involved in the various forms of cells under consideration; but it may help us somewhat if at this junction we briefly consider the nature of the chemical changes which are believed to occur in such cells. As previously stated, much has been written on this subject, especially in recent years, but so far no very definite or satisfactory conclusions have been arrived at. As the practical experience gained during the last fifteen or sixteen years rather tends to confirm broadly the deductions of Dr. Gladstone and Professor Tribe with reference to the behaviour of electric storage cells, it will be of interest to give some extracts from their early and extremely lucid communications made to *Nature* concerning their investigations on these cells.

As the result of many experiments, these investigators arrived at the conclusion that the minium or red oxide of lead in a Faure cell suffers decomposition according to the formula $Pb_3O_4 + 2H_2SO_4 = PbO_2 + 2PbSO_4 + 2H_2O$. As both the lead sulphate ($PbSO_4$) and the lead peroxide (PbO_2) are insoluble in dilute sulphuric acid, these changes take place merely at the surface, and require time to penetrate into the interior.

In a Faure battery a plate consists of a superficial layer of mixed peroxide and sulphate of lead; the thickness of this layer is dependent upon the time during which the sulphuric acid has been allowed to soak into the oxide of lead. The proper formation of a secondary battery is a matter evidently depending upon very careful adjustment of conditions.

In a lead accumulator the energy stored up in the cell is determined mainly by the amount of peroxide of lead present. This appears to be obtained with the smallest amount of loss when the current is not too strong.

There would seem to be no commensurate advantage in continuing the current after the oxygen has ceased to be absorbed pretty freely, because the presence of some unoxidized sulphate of lead, although it increases the resistance rather impedes than promotes local action. On the other hand, however, it is necessary that the reduction of the minium on the opposing plate should be complete, because a mixture of lead peroxide and metallic lead would be peculiarly conductive to the production of

lead sulphate, and thus increase the resistance; while if any peroxide should escape destruction, it would diminish the electromotive force of the cell. From the foregoing it would appear probable, that the most economical arrangement would be obtained by making the minium to be hydrogenated much smaller in amount than that to be oxidized. On trying the experiment with only half the quantity they obtained a most satisfactory result, as far as the charging was concerned. The lead peroxide was found to react both on the lead plate that supports it and on the lead on the opposite plate. This action, however, is no drawback, as, if it were not for the formation of a film of sulphate of lead on the surfaces of both plates, this action would quickly cause the cell to lose its charge; but the formation of sulphate no doubt also forms a serious obstacle to further local action.

Messrs. Gladstone and Tribe found that the initial electromotive force of the Faure cell, when freshly prepared, averaged 2.25 volts; but after being allowed to rest for some little time, it was reduced to about 2 volts.

During a discharge, oxide of lead in the presence of sulphuric acid becomes sulphate of lead, according to the equation—

$$PbO + H_2SO_4 = PbSO_4 + H_2O.$$

To prove that the sulphate of lead formed on the discharge is reduced in the subsequent charging, the lead plate of a fully-discharged cell, which was found to have

51 per cent of lead sulphate combined with the spongy lead, was subjected to a charging current of 1 ampere for a period of sixty hours, and on examination no trace of sulphate of lead was found. From this it may be concluded that during the alternate discharging and recharging of a Planté or Faure cell, sulphate of lead is alternately formed and reduced on the lead plate, and that the plate itself is not seriously corroded. It would, however, appear desirable not to allow the whole of the spongy lead to be reduced to the condition of sulphate during the discharge, for two reasons—viz. first, because the supporting plate stands a chance of itself being acted upon, and thereby weakened, if there is not a sufficient excess of spongy lead; and second, because the presence of this excess tends to facilitate the reduction of the sulphate.

It has already been shown that sulphate of lead is produced by the local action that occurs during repose between the peroxide and its metallic supporting plate. The same local action also takes place during the charging of the elements, this sulphate in its turn being attacked by the electrolytic oxygen. In this way the absorption of oxygen during the forming of the peroxide plate ought never to come to an end. It has been shown that .55 cubic inches of oxygen liberated will form and oxidize 3.7 grs. (troy) of sulphate of lead.

Referring to Planté's statement that an elevation of temperature facilitates the formation of his cell, Messrs. Gladstone and Tribe found that the character of the chem-

ical changes which take place at the negative plate led them to think it exceedingly probable that this increase in the rate of formation arose from an augmentation in the amount of local action. By experiment such was shown to be the case. Pairs of similar peroxide plates made on Planté's model were allowed to remain idle at 11° C. and 50° C. respectively, and the formation of the white sulphate was visibly more rapid at the higher than at the lower temperatures. The same was found to be true with negative plates prepared by Faure's process. Two plates of similar polarity were kept in repose for an hour, the one at 11° C. and the other at 50° C. On analysis it was found that respectively 2.6 and 7.4 per cent of lead sulphate had been formed. On two other plates the proportions were 7.6 and 9.5 per cent respectively. These observations, of course, do not by any means exclude the idea that an increase of temperature may also facilitate the other chemical changes that occur in the formation of lead-lead peroxide cells.

From the results obtained from their investigations, Dr. Gladstone and Prof. Tribe were led to the following deductions, viz.:—

1. In the Planté or Faure cells local action necessarily takes place on the peroxide plate, with the production of sulphate of lead.

2. The formation of this sulphate of lead is absolutely requisite in order that the charge should be retained for a sufficient time to be practically available.

3. The rapidity of loss during repose will depend upon the closeness of the sulphate of lead, and possibly upon other mechanical conditions.

From the foregoing it may be thought that the chemical action of storage cells is well understood and easily ascertained. Such, however, is not the case. The reactions involved are highly complicated, and vary considerably under various conditions incidental to charging and discharging, rates of charge and discharge, variations of temperature, and methods of manufacturing the active material, also the density and composition of the electrolyte. In fact, Sir Edward Frankland correctly puts the case when he stated that "the physical qualities of the cells are capable of very accurate estimation and investigation. But when you come to attempt to ascertain the chemical changes that occur in the charging and discharging of a storage cell, you encounter formidable difficulties. The outsider has no idea of these difficulties. Nothing seems more simple than to determine the chemical changes that take place in either the positive or the negative plate of a storage battery. It is not so in reality. The substances used as active materials are in the first place mixtures, and the materials obtained at the end of the reactions are also mixtures, and these mixtures are insoluble in any reagent which does not decompose them. They cannot be volatilized; they cannot be subjected to any process of solution and crystallization in order to separate and purify their elements."

Whatever difference of opinion may exist as to the chemical **reactions** of storage cells, for practical purposes they may be treated as the older and better known primary cells. In many cases these may vary considerably in point of mechanical construction, yet, theoretically, they appear to be governed by the same general laws. A fully-charged storage cell acts much in the same way as a primary cell when newly set up. The storage cell, however, has this great advantage, in that when discharged it can be again brought to its original condition by means of an electric current.

CAPACITY AND EFFICIENCY OF STORAGE CELLS

The total current, and the total energy capacity, of a storage cell is the maximum amount of current or electrical energy which it is capable of storing, without reference to any loss that may occur by it being allowed to remain idle, nor does it take into account the rate or manner of its discharge.

The working current, and the working energy capacity, is that amount of current, or electrical energy, which can be obtained from the cell at any specified rate of discharge. When estimating this, the discharge is always stopped as soon as the cell ceases to do useful work. The working capacity of storage cells may vary between very wide limits.

The absolute current, and the absolute energy efficiency,

of an accumulator cell is the ratio between that amount of current or energy put into it and that obtained by a total discharge, without reference either to its rate of charge or discharge, or to the time allowed to elapse between these operations.

The working current, and the working energy efficiency, of a storage cell is the ratio between the value of the current or energy expended in the charging operation, and that obtained when the cell is discharged at any specified rate.

In a lead storage cell, if the surface and quantity of active material be accurately proportioned, and if the discharge be commenced immediately after the termination of the charge, then a current efficiency of as much as 98 per cent may be obtained, provided the rate of discharge is low and well regulated. In practice it is found that low rates of discharge are not economical, and as the current efficiency always decreases as the discharge rate increases, it is found that the normal current efficiency seldom exceeds 90 per cent, and averages about 85 per cent.

As the normal discharging electromotive force of a lead secondary cell never exceeds 2 volts, and as an electromotive force of from 2.4 to 2.5 volts is required at its poles to overcome both its opposing electromotive force and its internal resistance, there is clearly an initial loss of 20 per cent between the energy required to charge it and that given out during its discharge. The normal discharging potential seldom exceeds 2 volts, and as this pressure con-

tinually decreases as the rate of discharge increases, it follows that an energy efficiency of 80 per cent can never be realized. As a matter of fact, a maximum of 75 and a mean of 60 per cent is the usual energy efficiency of lead-sulphuric-acid storage cells.

Planté found that peroxide of lead, when electrolytically prepared, gave 1 ampere-hour capacity for every 70 grs. (troy) of the salt. These figures have been substantially confirmed by more recent investigators. According to this we should expect to obtain approximately 100 ampere-hours capacity per pound of positive active material used. In practice, however, this high value is never attained. Sixteen ampere-hours per pound of positive active material is more nearly the best capacity obtained in practical work—in fact, this is seldom reached. This great difference is principally due to the fact that the larger part of the material employed is inactive in the way of producing electrical energy, and merely serves to cement the real active material together and retain it on its metallic support. The loss is also partly due to the fact that it is not economical to use to the fullest extent all the energy stored. In discharging cells it is usual to stop before the pressure at the terminals falls to such a degree as to interfere with the work it is expected to perform. This limit may vary widely, and is entirely dependent upon the work which the cell is constructed to do.

The E. P. S. Batteries.—Owing to defects which speedily developed themselves in Faure's early pasted plates,

they never came into commercial use. It was found that by repeated charging and discharging, the loose lead salts tended to permeate through the pores of the felt, and thereby induced the formation of lead trees. These minute metallic bridges caused serious short-circuiting, and ultimately led to the destruction of the elements. The inert porous separating medium, therefore, had to be abandoned, and the short-circuiting difficulty was overcome by leaving a clear liquid space between each pair of plates.

Many plans have been suggested and much ingenuity

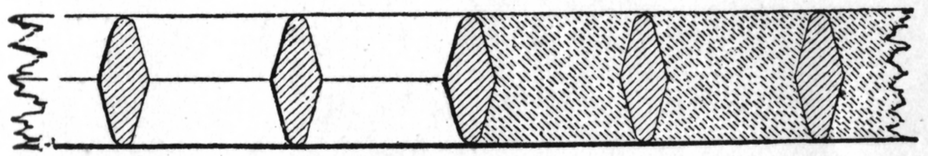

FIG. 6.—E.P.S. GRID

has been exercised in devising methods of holding active materials on to metallic accumulator elements.

With the knowledge gained from a very large number of experiments, the present form of grid, Fig. 6, was adopted. The usual method is to cast the grids in an iron or steel chill or mould. The elements now in use are perforated with a large number of square apertures, which are tapered inwards from both surfaces of the plate, thus forming a double dove-tail. Owing to their peculiar shape, the pellets of active material tend to key themselves firmly into the countersunk holes.

The negative plates are made of pure lead, and the early form of positives of an alloy of lead and antimony. The

antimony was introduced to make the grids hard and less liable to bend, and at the same time to prevent the "eating-in" action of the acid and current. The metal antimony is not dissolvd by a sulphuric acid solution, nor is it much affected by the electrolytic action; the more recent positive grids are made of pure lead. When cast and cleaned up, the grids are filled in with a paste made

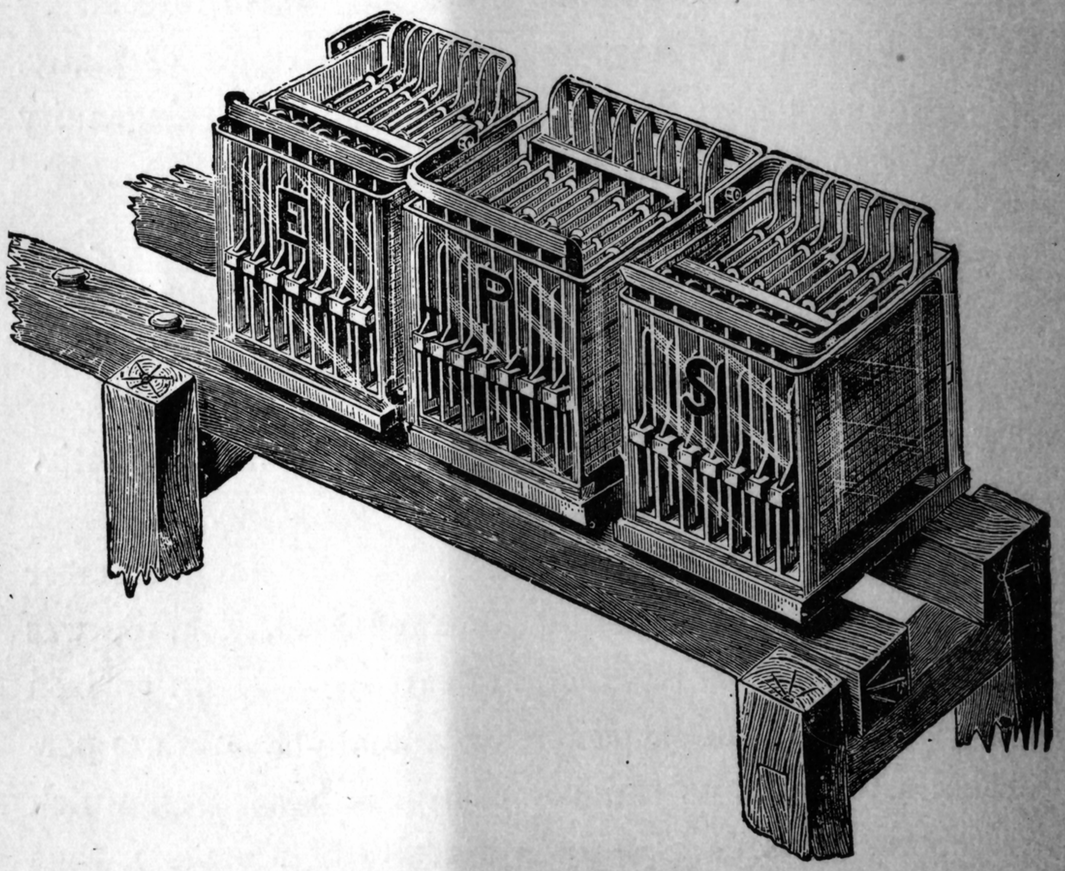

FIG. 7.—E.P.S. ORDINARY LIGHTING CELLS

by adding to minium, water acidulated with sulphuric acid. When dry the plates are placed in a bath containing dilute sulphuric acid, where they are partly formed, or what is known as "hardened," by means of an electric current. In all cases the actual forming is done by the purchasers.

In mounting these and similar types of cells in glass boxes, it is usual to place them in wood trays which contain a layer of sawdust to give the glass an even bearing. Each of these trays rests on four glass insulators, one placed under each corner. When fixed up for work, the cells are invariably mounted on wooden stands, as shown in Fig. 7. As a protection against acid fumes or spray, the wood stands are either well shellac-varnished or treated with anti-sulphuric-acid paint.

Of late years improvements have been made in the original E.P.S. plates. The King-Faure plate, now much used, has a series of ledges cast upon it on both sides, and these ledges are filled in with the active material. Plates made on this principle are much thicker than those originally made, and are said to give a greater capacity per pound of plate.

In Fig. 8 is shown one of the high-discharge cells, as used in central electric-light stations or electric railway supply works. The capacity in ampere-hours of these cells, when discharged in five hours, is given as 90 per cent of the nominal, and when discharged in three hours, at about 75 per cent, the full capacity of the battery being based upon a seven-hours discharge.

Another form of cell, designed for motor-cars and similar purposes, is shown in Fig. 9.

The "Hart" Accumulator.—This form of element has

been much in evidence lately. The plates used for central station work and ordinary electric lighting are made of cast-lead and built up on the girder principle, with lattice-work arranged alternately on either side and diagonal ribs running across the plate. The active material em-

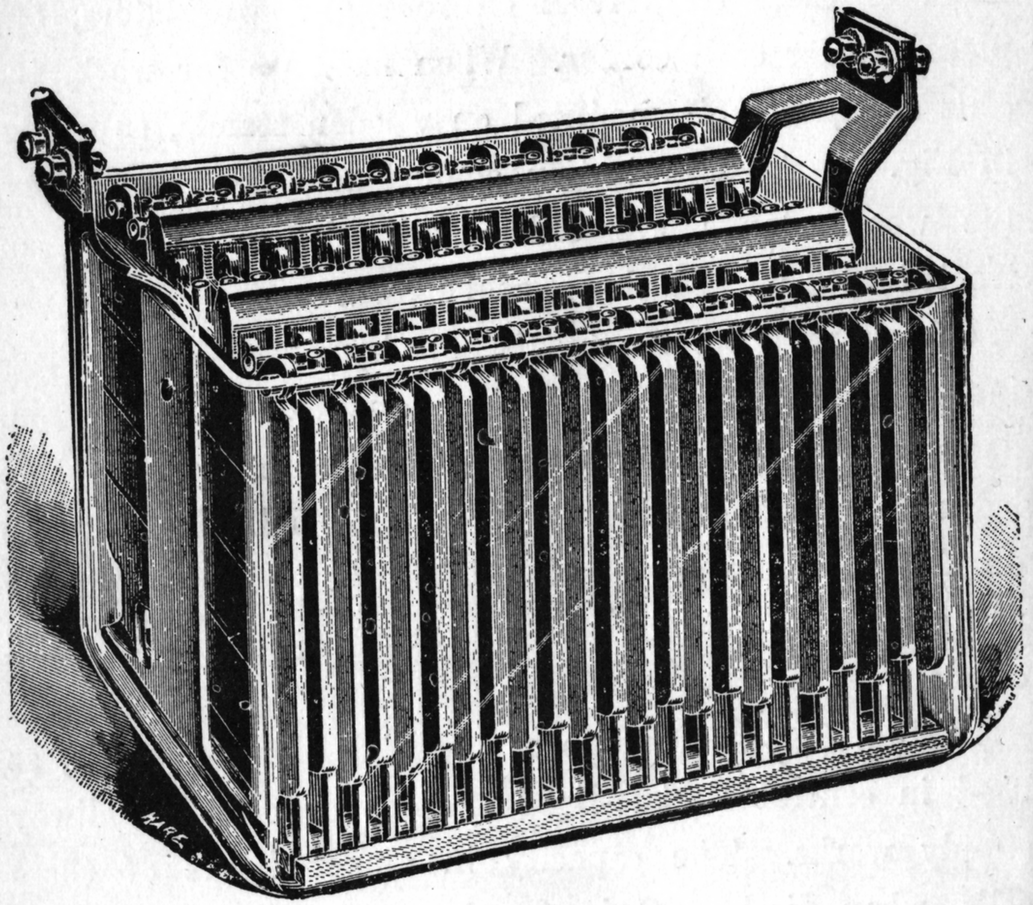

FIG. 8.—E.P.S. HIGH-DISCHARGE CELL

ployed is minium on the positive plate and litharge on the negative. By the mechanical arrangement of the plate, the active material in each is split up into a number of small pellets, a special feature about the plates being that each pellet is gripped hard on its surface by means of a leaden lip attached to the grid and turned over by a spe-

cial process. Each plate is provided with projecting lugs on either side, as shown in Fig. 10.

These lugs, as shown in Figs. 11 and 12, serve to support the element in the cell, as they rest on side-pieces of stout glass, thus keeping the bottoms of the plates quite

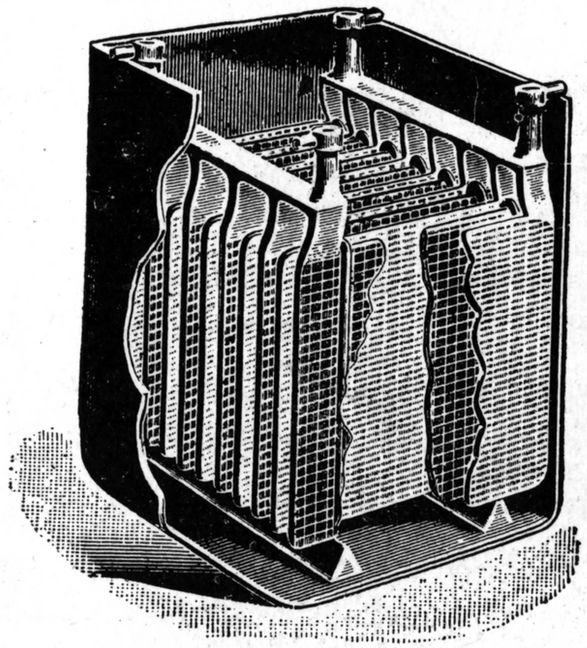

FIG. 9.—E.P.S. TRACTION CELL

free and some distance from the bottom of the containing cell.

The "Hart" cell has been much used recently in connection with the train-lighting system, as carried out by several railway companies. When used for such purposes, the lattice-type plate is only used for the negative element, the positive being a thinly-ribbed plate rather than a grid, the interstices of which are filled up level with the surface with the active material.

In storage batteries where the grid form of plate is

employed some rather weak points have developed themselves. In the case of the negative element but few difficulties have occurred, as with these plates, if the apertures were properly filled in and then thoroughly formed,

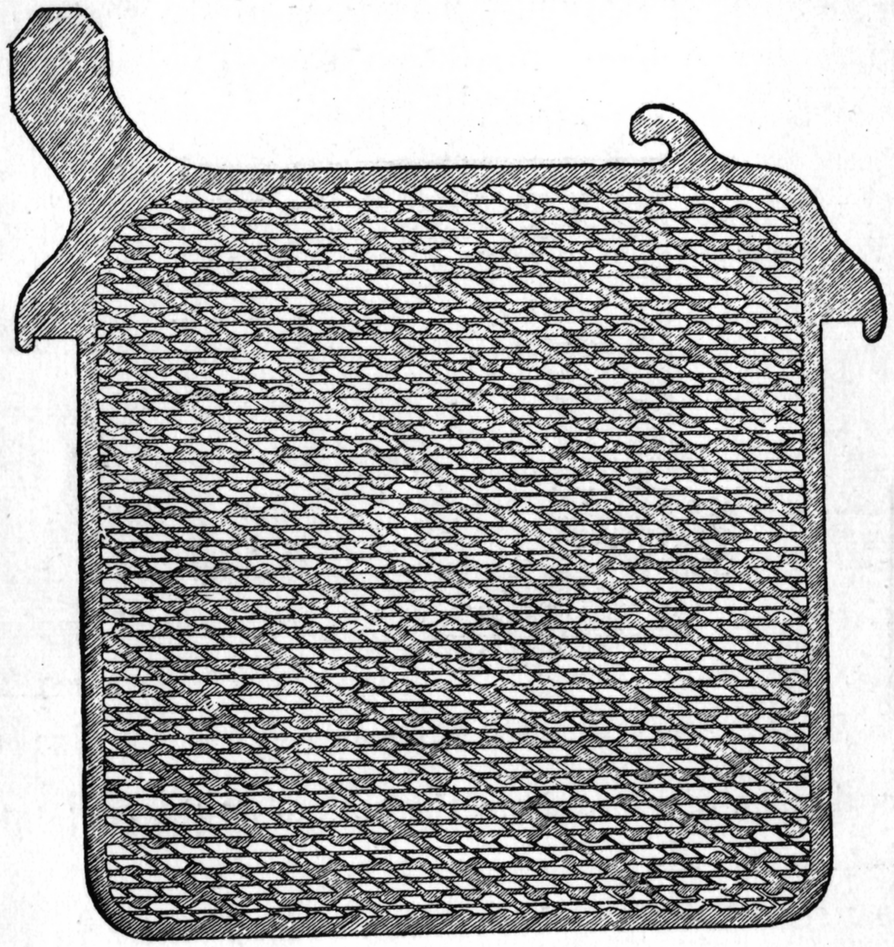

FIG. 10.—HART PLATE LIGHTING TYPE

little or no mechanical alteration occurs either during formation or subsequent use. With the positive elements the case is somewhat different; here, during the electrolytic formation, the lead oxides undergo a considerable amount of expansion, this increase of bulk being stated by some investigators to amount to somewhere between 5

and 10 per cent of the original mass. Unless, therefore, proper precautions are taken to ensure a uniform expansion in the lead salts, the comparatively rigid grid is liable to suffer considerable distortion. To counteract this distorting influence, the grids may be made mechanically strong either by increasing their thickness, or by introduc-

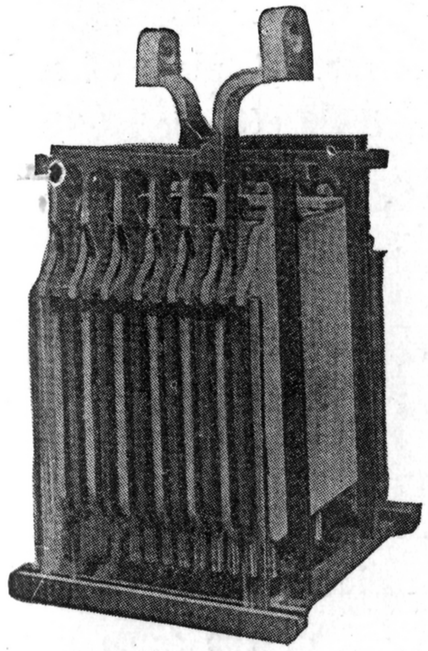

FIG. 11.—HART SET OF ELEMENTS

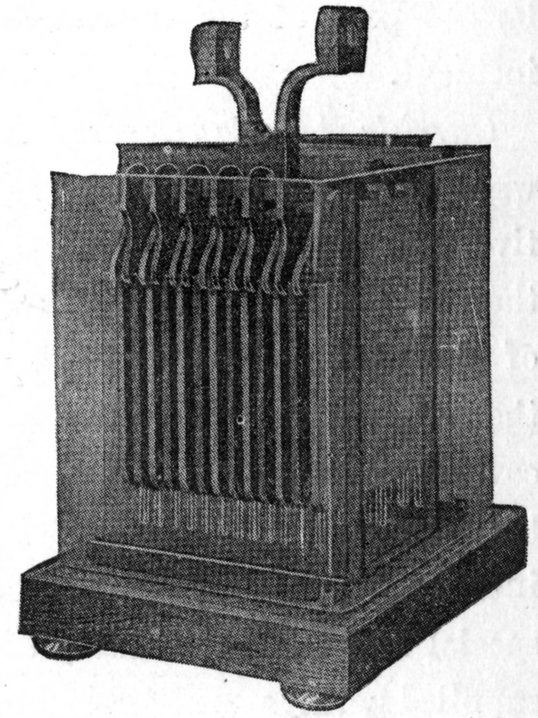

FIG. 12.—HART COMPLETE CELL

ing some hardening substance into the composition of the metal.

As already shown, the pellets of peroxide in the E.P.S. hard-metal grids are keyed in by the peculiar truncated shape of the holes. If the walls of these apertures are too acute, and if the expansion of the active material has

not been allowed for, there is a tendency for the little masses of oxide to split and to drop out.

Many attempts have been made to overcome the above-mentioned difficulties. Among these are the methods of running molten metal around suitably-shaped masses of lead oxide or peroxide, or by casting each grid in two parts, and then fixing them together in such a way that the largest part of the truncated holes in each part are co-incident.

Currie's Asbestos-Covered Elements.—A plate of somewhat curious form is due to Mr. S. M. Currie. The active material is in a thin layer, no part of it being more than one-eighth of an inch thick. The principal feature of this form of plate, however, resides in the fact that the active material is entirely encased within a sheath or covering of asbestos. The asbestos is first braided in tubular form and of the required thickness, and then cut up into suitable lengths, eight of which are placed in a special mould. Each tube, when placed in the mould, is supplied with a removable brass rod of the same length as the asbestos, but of considerably less diameter, which passes up its centre. By means of a suitable inlet a fused salt of lead, such, for instance, as the chloride of lead, is poured into the mould and fills up the intermediate spaces between the brass rods and the asbestos envelope. The rods are then withdrawn, leaving afterwards the chloride of lead in a compact cylindrical form, with an outer coating of braiding asbestos. The next step is that of filling

with pure lead, or an alloy of lead and antimony, the spaces lately occupied by the brass rods, and at one and the same operation casting on a connecting-bar of the same metal to hold the rods the requisite distance apart and to form the necessary connections. The chloride is re-

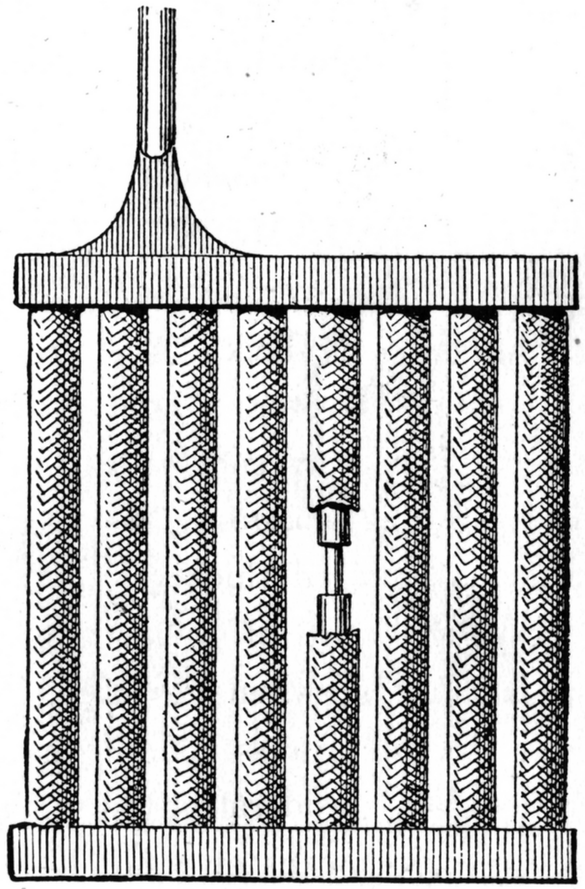

FIG. 13.—CURRIE'S ASBESTOS-COVERED ELEMENTS

duced to porous lead by electrolysis, after which the plate is ready to be fitted up and "formed". When formed in this manner these elements can be used in conjunction with positives of a similar type, or with flat positive plates of the ordinary type.

"Lithanode" Cells.—A material for making up elements for storage batteries quite distinct from any of those already considered is known as lithanode. It is produced from litharge made into a pasty mass with a solution of sulphate of ammonia, which causes the ma-

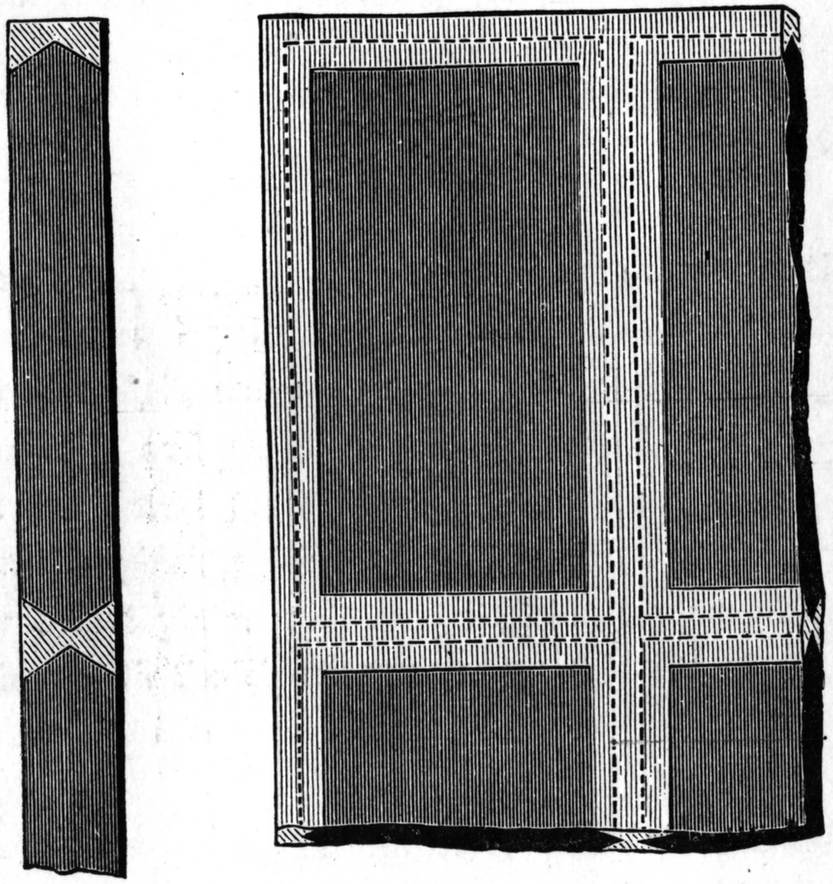

FIG. 14.—EARLY FORM OF LITHANODE PLATE

terial to "set", so that it will no longer disintegrate when placed in a fluid. In ordinary practice the elements are made up of a number of small slabs of lithanode, whose outer edges are V-shaped. These slabs or pellets are arranged in a casting mould of any suitable dimensions, and are placed at such a distance apart and from the edges

of the casting frame as to allow of sufficient space for the requisite quantity of metal to run in and impart adequate mechanical strength to the completed element. After the pellets have been arranged in this manner, an alloy of lead and antimony is run into the interstices, and thus a complete plate is formed, as shown in Fig. 14.

Before being cast up the positive pellets are converted

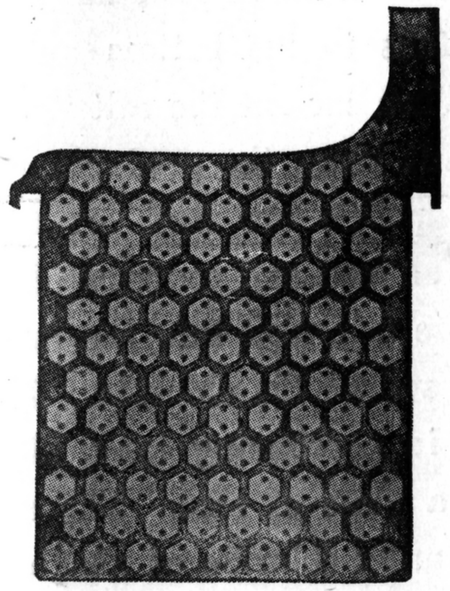

FIG. 15.—CHLORIDE NEGATIVE PLATE

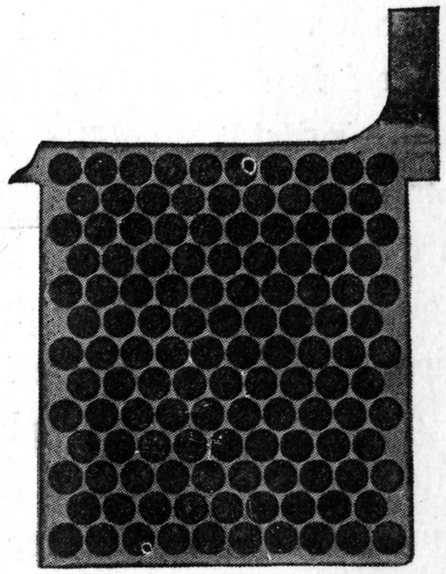

FIG. 16.—CHLORIDE POSITIVE PLATE

into peroxide of lead in a forming bath; those for the negative plates are simply dried and cast up direct, being reduced to a condition of spongy lead by the ordinary electrolytic method.

Chloride Storage Batteries.—In this case, instead of using litharge, chloride of lead is employed to make the pellets. The method of making chloride plates is somewhat as follows:—Litharge is dissolved in acetic acid;

which gives a resultant compound of acetate of lead. By adding hydrochloric acid to this solution, chloride of lead is precipitated. The precipitate is next passed through a filtering press, which squeezes out the liquid and leaves the chloride of lead in the shape of cakes. The cakes of chloride of lead so prepared are dried and put into melting-pans with a small percentage of zinc, which reduces some of the lead and forms a mixture of lead and zinc chlorides. The molten lead falls to the bottom and is run off from time to time. When melted the salt is run into a suitable mould, the result being the production of small hexagonal pellets. The pellets are next arranged in a metal chill, and an alloy of lead and antimony in a molten state and under pressure is forced into the interstices. The next process is to reduce the chloride. This is done by placing the plates in a reducing tank, alternately a cast plate, and then a plate of zinc. The zinc combines with the chlorine, forming chloride of zinc, and reducing the lead salt into pure spongy lead. Originally both the positive and the negative elements were made in this way, the spongy lead in the positive plate being converted into peroxide by the usual electrolytic method. In the United States the original manufacturers of chloride cells, the Electric Storage Co., have abandoned the above method of constructing their positive element, and, following out the prevailing fashion, the chloride plate is only used as the negative element; the positive is of different construction, and is of the Planté type. The positive plate, which is cast in a mould, has a large number of holes in it. These are about three-quarters of an inch in diameter, and slightly tapered outwards on both sides of the plate. Into the cast holes are pressed small rosettes of lead. These, which exactly fit the holes, consist of lengths of pure lead-strip gimped, and rolled up in the form of small coils. When all the apertures are filled in

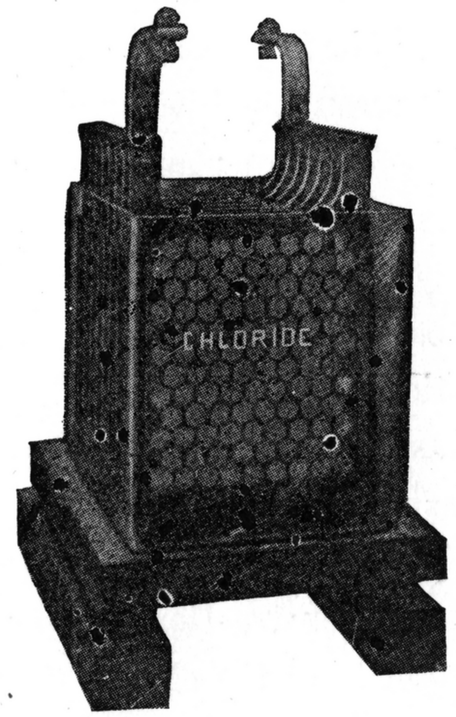

FIG. 17.—CHLORIDE COMPLETE CELL

the plates are submitted to pressure in a hydraulic press, which operation keys in the rosettes.

Mechanically Solid Batteries.—There can be no doubt that at present an inexpensive and mechanically solid storage battery is a great desideratum. There is an enormous scope for a cell which will combine large capacity and small

weight, which will withstand without injury high rates of charge and discharge, and possess in addition great mechanical strength and solidity.

Great hopes were entertained at one time that the solidity problem had been solved by the introduction of Dr. Schoop's elastic electrolyte. One great drawback to the employment of a viscous or gelatinous electrolyte resides in the fact that, when such substances are used, no free circulation of the liquid is possible. We have already seen that the activity of secondary battery elements depends entirely upon chemical action; and as the electrolyte is the medium through which all the necessary reactions take place, it seems highly probable that anything which prevents its free access to the active material must be detrimental to the action of the cell.

Niblett's Mechanically Solid Battery.—This cell in its original form was of the Planté type, and each element consisted of a highly cellular mass of material, which, owing to its form of construction, was capable of absorbing a sufficient quantity of the electrolyte for the due performance of all the necessary chemical reactions. Between the electrodes was placed a thin, highly porous inert diaphragm, which served to complete the solid character of the cell. The metal which constituted the elements was prepared by dropping red-hot molten lead into water, and was rendered active by the usual Planté method of formation.

Owing to the cellular nature of these elements the liquid contained within their pores was continually circulating throughout the mass, the slight evolution of gas accruing during the charge and discharge being quite sufficient to effect this.

The cellular construction of the elements gave them the peculiar property of automatically regulating their own internal resistance, for if the cell be charged at too high a rate, or when it is on the point of receiving the full complement of its charge, the gas generated tends to drive the electrolyte from the pores of the elements, and itself to remain imprisoned therein, thereby largely increasing the internal resistance. Much in the same way, as the discharge proceeds, the occluded gas re-enters into chemical combination, and allows the liquid to refill the pores, and thus exposes more active surface.

Lead-zinc, Copper, and Alkaline Storage Cells.—Hitherto we have only considered storage cells in which lead and lead compounds are used in the active materials. Many other combinations of metals and salts have been tried, and it is possible that it is in this direction that we must look for any startling and epoch-making development. It must be admitted, however, that so far only those cells in which lead and its salts have been used have proved a commercial success.

As previously stated, the value of peroxide of lead, when employed as a depolarizer in certain forms of primary batteries, has been known and appreciated for many years. On the introduction of Planté's and Faure's perox-

ide cells the interest of electro-chemists was re-awakened to this fact, and by experiment it was soon demonstrated that if a fully-charged peroxide of lead element, in conjunction with a zinc plate, be immersed in a solution of dilute sulphuric acid, a powerful electric current is obtained, which possesses a very high electromotive force. The chemical reactions involved in such a cell are doubtless of a somewhat complicated nature, but an analysis of the electrolyte of a discharged cell shows that the sulphuric acid combines with the zinc, forming sulphate of zinc, which passes into solution, and that the hydrogen gas liberated during the chemical combination attacks the oxygen in the lead peroxide and reduces it to a form of a lower oxide. In addition to this deoxidizing process there is the sulphating action of the lead compounds, which, as already explained, occurs during the discharging operations in all forms of lead-sulphuric-acid storage cells. During the recharging a reverse action seems to occur; the zinc is abstracted from its solution, and is deposited upon the zinc electrode, and at the same time the reduced lead oxide re-acquires its lost oxygen.

The chemical reactions during the charging operation are probably fairly represented by the following equation:—

$$Pb\,SO_4 + Zn\,SO_4 + 2\,H_2O = Pb\,O_2 + Zn + 2\,H_2\,SO_4.$$

According to Emile Reynier the chemical reactions of a discharge have two phases, which may be stated thus:—

At the outset one equivalent of sulphate is carried both to the positive and negative elements, as represented by the equation—

$$Pb\,O_2 + Zn + 2\,H_2\,SO_4 = Pb\,SO_4 + Zn\,SO_4 + 2\,H_2O.$$

During the second phase another equivalent of zinc is sulphated at the negative pole, and an equivalent of hydrogen reacts upon the positive element, during which operation the active material resolves itself into metallic lead and sulphuric acid, as shown by the following equation:—

$$2\,Pb\,SO_4 + Zn + H_2O = Zn\,SO_4 + 2\,Pb + H_2\,SO_4.$$

Immediately after a charge the electromotive force developed by a zinc-peroxide couple may reach 2.7 volts. During a discharge the internal resistance of this form of cell is found to vary between very wide limits. At the commencement it is about the same as that of the lead-peroxide couple, but as the discharge proceeds the resistance is continually being augmented owing to the conversion of the highly-conducting acid electrolyte into sulphate of zinc solution, which has a much higher specific resistance.

It has been found that if chemically-pure zinc is immersed in pure dilute sulphuric acid no combination occurs, the metal remaining quite unaffected. If, however, commercial zinc be used, which invariably contains, among other impurities, iron, lead, and arsenic, then the acid is found to quickly attack the zinc, and rapid combination

occurs. This action is probably due to the formation of innumerable minute galvanic couples between the true metallic zinc and the iron, lead, or other impurities; so that when commercial zinc is used as an electrode in a lead-zinc cell a considerable quantity of the electrical energy is dissipated owing to this form of local action. This

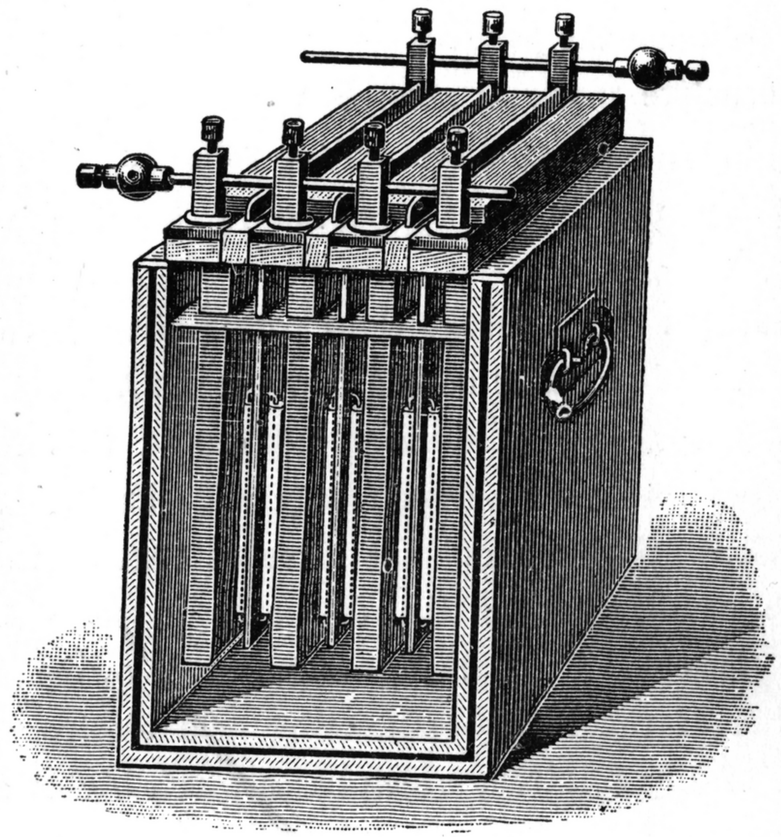

FIG. 18.—REYNIER'S ZINC-LEAD CELL

loss of energy not only occurs while the cell is in action, but is always going on, even if the cell be allowed to remain inactive, or during periods of repose. Thoroughly amalgamating the zinc is found to considerably reduce the tendency to local action.

Reynier's Zinc-Lead Peroxide Cell.—Among the first to practically develop the lead-zinc storage cell was the late Emile Reynier. In his form of secondary cell he employed an ordinary Planté or Faure peroxide plate, in conjunction with thin sheets of lead on which a thick layer of electrolized zinc had been deposited. By the utilization of pure electrolized zinc many of the difficulties arising from local action were eliminatel. A battery of this description (Fig. 18), introduced in the year 1884, was constructed as follows:—

Each cell contained four peroxide plates of the Planté type, which presented an extensive active surface, and three negative elements made of smooth sheet-lead, and covered with electrolized zinc which had been deposited from an acidulated bath of sulphate of zinc. When building up the cells accidental contact between the electrodes was guarded against by the insertion of glass insulating-tubes, which were secured to the negative plates by means of leaden strips. The seven electrodes were carried by cross-pieces of paraffined hardwood, which rested on the edges of the containing cell, and served to keep the elements in position. These cross-pieces were made of sufficient width to just touch one another, and thus they served the double purpose of holder and cover.

The following particulars of a cell of this construction were given by M. Reynier:—

Total area of active positive surface..3,100 sq. inches
Total area of active negative surface..1,325 sq. inches

Weight of positive elements.....	18	lbs.
Weight of negative elements.....	3	lbs.
Weight of containing-trough.....	6	lbs.
Weight of electrolyte.....	9.6	lbs.
Weight of connectors.....	1	lb.
Total weight of complete cell.....	37.75	lbs.

From a cell of this form of construction the following results were obtained:—

Electromotive force	2.36 volts.
Mean internal resistance	0.02 ohm.
Rate of discharge	25 amperes.
Rate of charge	5 to 10 amperes.
Capacity of cell after 200 hours formation	152 ampere-hours.

The Lalande and Chaperon Alkaline Cell.—Hitherto but little seems to have been done in the way of utilizing this cell as a medium for storing electrical energy, but as an economical primary generator it has been highly spoken of. It may therefore be of interest to briefly consider this form of cell, as it may serve to throw some light upon the more distinct types of alkaline accumulators.

Messrs. Lalande and Chaperon ascertained that oxide of copper was readily reduced to its metallic form when used in conjunction with zinc in an electrolyte of caustic potash. Their first copper elements were prepared by mixing small quantities of the oxychloride of magnesium with oxide of copper, and then, to ensure good electrical conductivity, this plastic mass was moulded on to a metallic support, and pressed into the desired shape. Electrodes constructed according to this method were found to expose a very large active surface, but as the resultant by-products were of little value they were soon abandoned. Accordingly it occurred to the inventors that far more economical elements might be prepared by applying the copper oxides to a conductor which was placed horizontally, and in such a manner that the copper salts merely rested loosely and lightly upon it. Cells of the horizontal gravity type were accordingly made, and in these the zincs were suspended in the upper part so that the dense solution of zincate of potash, when formed, sunk by reason of its density to the bottom of the cell and remained there, while the lighter and more active solution was free to attack the suspended zinc. The chemical destruction of the zinc plates, when placed under these conditions, was found to go on with perfect uniformity, and by experiment it was demonstrated that a zinc element, eight .3 inch thick, was consumed so regularly that it remained quite intact, and continued to expose its original surface area until it became reduced to only .078 inch in thickness.

The inventors found that caustic soda gave apparently the same results as the potash, both as regards the electromotive force and internal resistance, but as soda salts are liable to creep, they preferred to employ the potash. The

electromotive force developed by this cell is somewhat low, being only about 0.8 of a volt, but this is in a measure compensated for by a small internal resistance.

The following may be taken as representing the chemical reactions which occur during a discharge of the zinc potash-copper oxide cell:—

$$Zn + 2\ KHO + CuO = K_2ZnO_2 + Cu + H_2O.$$

PORTABLE CELLS

SEMI-PORTABLE AND PORTABLE STORAGE BATTERIES

Probably no individual type of secondary cell will be found to answer for the very varied and ever-increasing purposes to which this class of apparatus is now being applied, and it follows that some form of specialization must occur.

For central electric-light stations, or for such work as levelling up the loads on electric tramways, where moderately constant work is required, a battery whose weight is large, or whose bulk is great, may be safely used. For self-contained electric-light installations, weight and space occupied by the battery is of some moment; and where intermittent charging only is resorted to, absence of local action is desirable. The battery under these circumstances may have to stand idle for considerable periods, and it would not do for it to lose its charge while thus waiting. For traction purposes, where charging each day, or even several times per day, may be practiced, local action is not such an objection, and the loss sustained thereby may be neglected. For some forms of vehicles, which may be only occasionally used, and may have considerable waits between the periods of use—waits which may extend over days and even weeks—the absence of local action is essential. A fifth class of apparatus, in which storage batteries are now playing a most important part, is that of self-contained portable electric lamps, so largely used for medical and other purposes. In this case absence of local action, lightness and compactness, together with great mechanical strength, is absolutely essential. In many cases such cells are required to hold their current for many months, and this can only be obtained where there is little or no local action. Again, as the plates used in these small batteries are of small dimensions, the form of construction may be such as is not permissible in any other class of apparatus.

As a convenient means of obtaining an electrical current of small amount and of short duration, perhaps no electrical generator is so convenient and easily manipulated as a good form of primary battery. But, on the other hand, where cost is a consideration, or where comparatively large and continuous currents of uniform pressure are required, primary batteries are altogether out of the question.

In the best types of primary batteries zinc is used as the decomposable element, and zinc may therefore be regarded as the fuel of this particular form of cell. Sul-

phuric acid is generally employed as the excitant fluid, and some form of oxidizing agent as a depolarizer is required if only approximate constancy is aimed at. To produce a unit of electrical energy it is found that, excluding the cost of the depolarizer, zinc is fully twenty times as expensive as coal. Taking into account all losses in a secondary battery, and allowing for an efficiency of, say, only 50 per cent, it follows that for continuous and regular working for such a piece of apparatus as an electromotor for instance, the maintenance of primary batteries would come out fully ten times more costly than that of a secondary battery.

A subject which at the present moment is receiving a vast amount of attention is the various means of propelling vehicles over common roads. Not only is it of interest to electrical and mechanical engineers and carriage builders, but it has been taken into serious consideration by all those responsible for the regulation of traffic in our large towns. The subject is of such huge importance that it not only affects those whose business or pleasure calls for some rapid and safe means of transport from place to place, but it affects the safety and comfort of the ordinary pedestrian as well. Our present system of horse traffic is open to many objections, not only from a humanitarian point of view, but from its sanitarian and economic aspect as well. The streets in our large towns would present a vastly different aspect if, instead of horses, some other means of drawing our vehicles were used.

Much attention has been given to the application of steam, petroleum, and spirits to produce the necessary motive power: but there is but little doubt that electricity will eventually supersede them all, not only on the score of economy, but owing to its freedom from heat, steam, disagreeable odour, and to the ease with which it can be manipulated.

As to the probabilities of the self-contained electric motor-car comparing favourably with other methods, this will entirely depend upon its economic aspect. However great the convenience of electric power, however great its its reliability, ease of manipulation, sanitary aspect, and general convenience, the question as to whether it is best or not has still to be satisfactorily answered. In its present experimental stage trustworthy figures of the daily or weekly cost of up-keep cannot be expected. It is only by taking the average expenses incurred during months or years that anything like an accurate estimate can be arrived at. The initial cost and cost of maintenance of the batteries employed will be the controlling factor. Whatever turn the idea of electrically-propelled motor-cars may take, it must necessarily involve the use of some apparatus for storing and giving out electrical energy.

The desirable qualification of storage batteries of a semi-portable or portable character are—(1) Small weight, (2) Small bulk, (3) Great mechanical strength and durability, and (4) Capability of withstanding very high rates of charge and discharge.

The cells which we shall now briefly consider are especially devised with a view to fulfilling some, or all, of the above conditions.

The "Marschner" Cell.—This battery was recently tried on the Dresden railways. The plates were stated to consist of the ordinary oxides of lead, incorporated with powdered amber and an essential oil. This mixture was said to "set" very hard, the resultant plate being of a tough metal-like nature. On the Dresden cars 144 cells of this make were used. The total weight of the complete battery was given as 5,290 pounds. The current efficiency of the battery was stated to be over 90 per cent, and if discharged at its normal rate—that was, 65 amperes—an energy capacity of about 8 watt-hours per pound of complete cell was obtained.

Tommasi Cell.—M. Tommasi was one of the first to construct storage battery elements on the tubular plan. Most of these tubular elements took the form of a perforated tube made of lead or antimonial-lead, the inside being filled with active material. Recently a modification of this cell has been used for traction purposes in France and elsewhere with some degree of success. In the traction cell perforated celluloid is used instead of the lead. In the centre of this is placed a plate of antimonial-lead which forms the conductor. The intervening space is filled in with a semi-fluid paste of lead oxides. The advantages claimed for this construction are that disintegration of the active material is prevented, and that the metal

core only being used as a conductor and support it is protected in a measure from the corrosive action of the electrolyte by the lead oxides.

The "Sperry" Traction Cell.—This is an American production. The conductors are thin sheet-lead plates corrugated horizontally and then pierced with trapezoidal holes, so as to resemble a corrugated grater. The active material used is one of powdered lead 80 parts, and 20 per cent of lead oxide, to which is added a small quantity of an alkaline salt. The material is moistened, and applied to the conductor under a pressure of 1,000 lbs. per square inch, when a solid compact mass results. Before placing in the containing cell the elements are covered with a pyroxylin envelope, made from a coarse cotton cloth treated with a coating of pure cellulose. To prevent damage through jarring, the elements are placed in a vulcanite cell, and rest upon soft resilient ribs.

The Sperry cell is said to give 1.75 ampere, 9.187 ampere-hours, and 18.15 watt-hours per pound gross weight. at a 5.5-hour discharge, and 15.09 watt-hours at a 3-hour rate.

The Sherrin Cell.—This traction cell proved itself a success in the recent Automobile Clubs' Competition, and seems to promise well. The Sherrin elements are built of rods, deeply grooved on one side and twisted up much in the same way as an American twist drill. These rods are made of lead, and to give lateral springiness holes are drilled at intervals through the thinnest part of the

plate. To regulate the thickness of the layer of active material which is afterwards applied, a helix cut from an ebonite tube is passed over the metal core, and this serves likewise to support the paste. The idea is that the slight twisting and untwisting of the core and insulating helix provide for longitudinal expansion and contraction due to changes which may be produced during a charge or discharge. As an additional safeguard against damage, when the cells are used for motor-car work, a thin perforated vulcanite sheet is wrapped tightly round the rods. At the above competition this battery gave the highest mean efficiency, viz. 70 per cent, and it was said to be the only battery whose cells did not fall below the prescribed limit of 1.7 volt per cell.

Niblett's Traction Cell.—The metallic conductor used in this form of cell is of small dimensions and light weight. It forms the backbone of a frame wherein the active material is contained, and is so arranged that all those parts immersed in the electrolyte and not covered by the active material are insulated. By this arrangement all the lead salts are brought under direct electrolytic action, and therefore uniformity of formation is ensured both in the initial processes and also in the charging and discharging operations, and greater efficiency is obtained.

The material employed in both the positive and negative plates is not the usual lead oxides, but is a compound of lead salts produced electrolytically, and is of a conductive nature. When set and properly seasoned, the material is of a stone-like character somewhat resembling lithanode, but far more porous and conductive. The conductivity is obtained by incorporating with the ordinary chemically-prepared lead salts the electrolized oxides, and the porosity by mixing with the mass a small quantity of an infusorial earth. The latter material is obtained native, and consists of nearly pure quartz in a highly fibrous condition. This peculiar form of quartz is rather remarkable; it is exceedingly light, and is not affected even by concentrated acids at ordinary temperatures, nor is it decomposed by electrolytic action.

As in the case of lithanode, the resultant material produced by the above process is of such a coherent and hard texture that, as a positive plate it may be used in the form of blocks or slabs, the conductor being merely clamped on to it, or it may be made in the form of pellets and have the metal conductor cast around it in the ordinary way.

As separators between the elements a new material of a highly porous nature is used. This mixture is composed of kaolin and the same kind of infusorial earth as used in the active materials. This composition, when mixed and thoroughly burned in a kiln, is exceedingly hard yet highly porous.

By adopting the thin, rigid, porous, earthenware separators, all possibility of short-circuiting is obviated, and the plates may be brought very closely together.

A somewhat curious feature with reference to the above form of cell has been noticed. When on discharge, should

the containing-box in which the elements stand become broken and all the electrolyte escape, the cell will still go on discharging for a considerable period without in any way showing a falling off in its discharge rate. It is found that sufficient electrolyte is retained in the porous separators and material to allow all the requisite chemical reactions due to a discharge to go on. Tests have been made with sets of fully-charged elements which have been entirely removed from their electrolyte and thoroughly drained. In some cases as much as 50 per cent of the available energy at normal discharge rates has been obtained from cells so treated. This feature is of some importance, especially in cells used for traction or motor-car work, or under conditions where a broken containing-box would be liable to produce a complete break-down.

The Fulmen Traction Cell. The following description of this well known cell will serve to make plain the details of its construction, and operation. Small oblong pellets of the material are placed in a mould, and are converted into plates by running molten antimonial-lead round them. In the cells made for the Paris cab trials were six positive plates and seven negative. The total weight of each positive plate was 16½ ounces, and of this about two-thirds consisted of the slabs of active material. The negatives each weighed 13½ ounces; 4½ ounces of this was metal support. The total exposed area of positive surface was 325 square inches, and the total weight of the complete cell was 16½ lbs. The normal discharge was

21 amperes, and at this rate the cells are said to have had a capacity of 105 ampere-hours, the current capacity being 6.4 ampere-hours per pound of complete cell.

Bristol's Batteries.—Bristol constructs elements by incorporating oxides of lead with binding material, such as asbestos fibre, animal hair, horn shavings, or some similar fibrous substance, which is capable of giving the mass just sufficient cohesiveness to retain its shape without the aid of a metallic support. The salts of lead, when mixed with from 1 to 3 per cent by weight of the fibrous material, are found to have sufficient mechanical strength to resist all ordinary disintegrating influences either mechanical or electrical. When the binding material has been thoroughly incorporated with the metallic oxides, it is moistened and made into a stiff pasty mass and pressed into moulds to give it the desired shape, and either a flattened lead wire or a platinum strip having lateral branches is inserted within the soft mass to act as a conductor. When dry, the masses are "formed" in an acid bath by the usual method. Distance-pieces of wood saturated with paraffin-wax are placed between the plates to keep them the proper distance apart.

The Pescetto Cell.—This cell is an Italian production, and is said to derive its superiority from the highly porous nature of the active material used. The metalilc supports are of the grid pattern, and each aperture has prongs extending from the cross-bars. The lead oxides are mixed with a material made by boiling sugar in dilute sulphuric

acid. The same material is used for both elements. It is said that during the forming operation this binding material is eliminated, thus leaving the mass in a highly porous state. The cells are made up in three distinct types, so as to fit them for various rates of discharge. Thus, we find that a range of from 0.69 to 6.9 ampere-hours per pound of cell is obtained, while the period for recharging is said to range from 7½ hours down to 15 minutes. The energy capacity is said to vary between 8.85 and 2.28 watt-hours per pound of complete cell according to the nature of the material employed.

The Gulcher Cell.—This form of cell, known as the "Woven-Glass Cell", differs somewhat from the general run in that its conductive support is not entirely composed of metal. The supporting frame is of the "mesh" type, and in its construction parallel wires of lead are interwoven with threads of exceedingly fine spun glass. The wire is used as the "warp" thread, and the spun glass as the "woof". The active material on being pasted on to this support entangles itself in its meshes, and becomes firmly secured.

When assembling the elements pads of glass-wool, similar to that used by chemists to filter acids, are placed between the plates, thus preventing the active material from detaching itself from its support. Plates built up on this plan have been, it is said, largely used with much success by several German firms of traction engineers.

Pitkin's Portable Accumulators.—The Pitkin elements

are very simple in construction. They consist of small cast-metal plates, each having an outer raised rim on both of its sides, and a number of small tapered pins of the same height studded over its entire surface. To retain the plates at the requisite distances apart, and to prevent bending and warping, small round vulcanite pins are screwed into the extremities of the positive plates, and are cut off of just sufficient length to allow them to slip tightly down between the two negative plates. Minium made into a stiff paste with dilute sulphuric acid is used for both positive and negative plates. The forming is carried on in the usual way.

Boese-Lutcke Traction Cells.—This is another of the traction cells in which solid blocks or slabs of active material are used. Litharge is used for the negative and minium for the positive plates. These oxides are made into a paste by being mixed with a compound made from anthracene dissolved in pure alcohol. The anthracene mixture is made by boiling this material in dilute acetic acid until it becomes a syrupy mass, when minium is added to it, and it is again boiled until the lead salt is entirely dissolved. A small quantity of this compound is mixed in alcohol, and this forms the solution for producing the paste. After being moulded into the desired shape, the elements are pierced with small holes to give them porosity, and when dry and seasoned, the pellets are placed in a mould and lead, or antimonial-lead is run in around them. The lead oxides prepared in the above manner harden very

quickly, and it is stated that the drying operation only takes a few hours.

The "Lecoil" Traction Cell is somewhat of a departure from the ordinary run of traction cells. In one form used for working a motor-car, each cell contains ten cylindrical porous pots constituting a set of positive elements. In each of these porous vessels is placed a metal core. The core is centrally fixed, and the whole of the space is then filled in with lead oxides in a pasty condition. Surrounding each of these solid elements is a thin copper gauze cylinder; these when joined up constitute the negative element. The solution used is said to be a mixture of the sulphates of cadmium, magnesium, and zinc. During the forming the oxide in the porous vessels is converted into peroxide, while the zinc, and probably the cadmium and magnesium, are deposited on the copper mesh. During the discharge the oxide of lead is reduced in the ordinary way, and the metal on the copper re-enters into solution. The open E.M.F. when newly charged is given as 2.55 volts per cell, and the energy capacity is 12 watt-hours per pound of complete cell. Another advantage claimed for this cell is that it can be discharged at very high rates without injury, and also that the presence of the cadmium and magnesium prevents the violent local action so destructive to most forms of lead-zinc cells.

The Edison Motor-Car Cell.—The following description of this cell is given by Dr. Kennelly.

"The negative pole or positive element is iron, the positive pole or negative element is a superoxide of nickel believed to have the formula NiO_2. The electrolyte is potash, viz. an aqueous solution containing from 10 to 40 per cent by weight, but preferably 20 per cent, of potassium hydroxide.

"The initial voltage of discharge after recent charge is 1.5 volt. The mean voltage of full discharge is approximately 1.1 volt. The normal discharging current rate per unit area of active element (positive or negative) is 8.64 amperes per square foot. The storage capacity of the cell per unit of total mass of the cell is 14 watt-hours per pound of battery. The mean normal discharging power-rate per unit mass of total cell is 4 watts per pound, corresponding to a normal discharge period of 3½

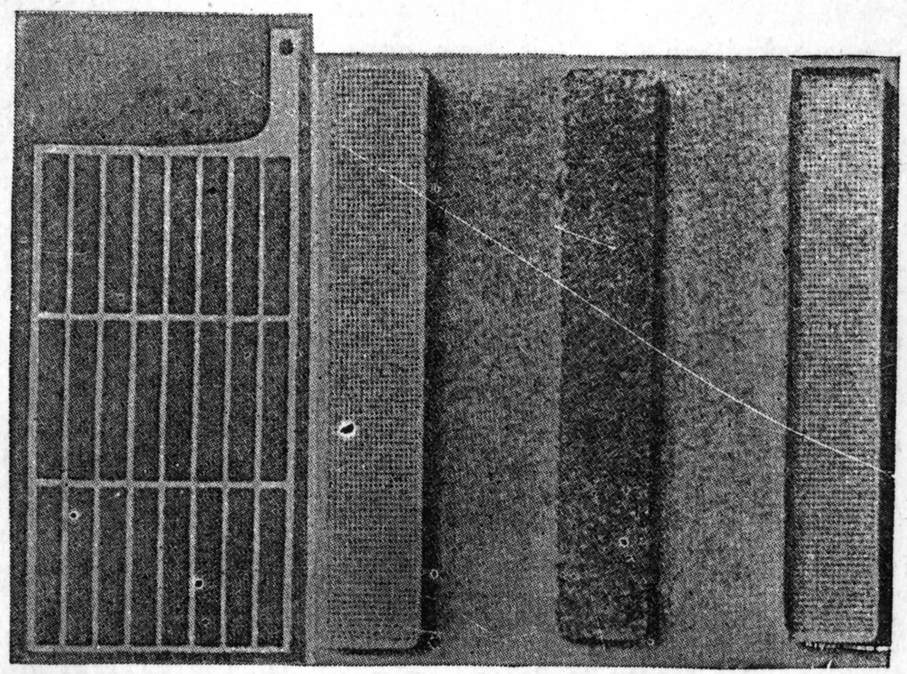

FIG. 19.—EDISON'S ELEMENTS

hours. The cell may, however, be discharged at a relatively high rate, in approximately 1 hour, corresponding to a discharging power-rate per unit of total cell mass of 12 watts per pound."

"Each plate is formed of a comparatively thin sheet of steel, 0.024 inch in thickness, in which rectangular holes are stamped, so as to leave a grid or frame, somewhat resembling a window-frame. Each opening or recess is filled with a pocket or shallow box containing the active material. These pockets are perforated with numerous small holes to admit the electrolyte, but entirely conceal the contained active material from view."

"The active material is made in the form of rectangular cakes or briquettes, and one such briquette is lodged in each pocket or 'window-pane' of the plate. Each of the plates, therefore, supports, or contains, twenty-four briquettes of active material, all in rigid contact with its own substance. Each briquette is placed in a shallow, closely-fitting nickel-plated box of thin perforated crucible steel, cut from a long strip of that material 0.003 inch thick. A cover or lid of the same material is then laid over it, so that the briquette is closely enveloped by the sides and walls of its perforated steel box. The boxes are then placed in the openings or holes in the nickel-plated steel grid, and closely fit the same. The assembled plate is then placed in a hydraulic press and subjected to a total pressure of about 100 tons. This pressure not only tightly closes the boxes, but it also forces their metal sides

over the adjacent sides of the recesses in the steel grid, thus clamping the whole mass into a single solid and rigid steel plate, with the hollow 'window-panes' full of active material. The finished plate has a grid thickness of 0.024 inch, and a 'window' or pocket thickness of 0.1 inch (2.5 mm.)."

"The positive briquettes are made by mixing a finely-divided compound of iron, obtained by a special chemical process, with a nearly equal volume of thin flakes of graphite. The graphite does not enter into any of the chemical actions, but assists the conductivity of the briquettes. The graphite is divided into very thin laminæ by a chemical process, and these are passed through sieves or screens so as to leave a size and area of flake that is much larger than the area of the perforation in the steel windows. The mixture is then pressed into briquettes in a mould, under a hydraulic pressure of about 2 tons per square inch. The briquettes have a surface area of nearly 3 inches by 1½ inch on each face."

"The negative briquettes are made by similarly mixing a finely-divided compound of nickel, obtained by special chemical means, with a nearly equal bulk of fine flakes of graphite, and solidifying the mixture in a mould into briquettes of the same size as above."

"In charging, the current deoxidizes or reduces the compound to spongy metallic iron, and carries the oxygen through the film of electrolyte to the nickel compound, oxidizing it to the superoxide of nickel, NiO_2, a higher

oxide than the peroxide. In other words, the charging current simply carries oxygen in the opposite direction, against the forces of chemical affinity, from the iron to the nickel, and stores the energy in the reduced iron, which is, of course, unaffected and passive in the presence of the potash solution. On discharge, the oxygen moves back against the current and partially reduces the nickel superoxide NiO_2 while oxidizing the spongy iron."

"In the new Edison cell the theoretical action of the potash solution is merely to provide the proper channel through which the oxygen irons may travel in one direction or the other—positive plate to negative plate in charge, and negative plate to positive plate in discharge. Consequently the amount of solution needs only to be sufficient to fulfil the mechanical requirements. It is believed that the weight of solution will in practice be only about 20 per cent of the plate weight or about 14 per cent of the cell weight. In fact, the cell may be worked in the same manner as the so-called primary 'dry-cells'. Moreover, if the solution should escape or be carried away, by gassing in charging, the only detriment seems to be the loss of active surface thereby occasioned, and it will only be necessary to fill up the cells to the proper level with water from time to time, as evaporation or gassing may lower the level. For the same reasons, the specific gravity of the electrolyte does not appreciably vary during charge and discharge."

"The briquettes of active material slightly expand on

receiving oxygen, and slightly contract on delivering it. The level of the solution is in this way scarcely affected. The expansions and contractions of the briquettes appear to be well within the elastic limits of the spring-steel containing-boxes, and consequently the electric contact is always secure. The covers or sides of the window-pockets merely approach to, or recede from each other slightly during charge or discharge. Fortunately, steel is the metal which possesses this mechanical elasticity in a marked degree."

Classes of Batteries.—Batteries used on electric vehicles can be divided into two classes: those used for pleasure vehicles, and those used for commercial delivery wagons and trucks. The type of battery is, in general, the same. In commercial service, however, the batteries run to much larger sizes, and, in consequence of this, as well as the less resilient spring and tire action, they are of necessity assembled in a more heavy and substantial manner. Storage batteries consist of the following elementary parts: positive plates, negative plates, separators, straps, jars, covers, connectors and crates.

Sizes of Plates. The plates are made of different sizes, but the two sizes most used are the MV, 8⅝ inches high by 5¾ inches wide, and the PV, 8⅝ inches high by 4¾ inches wide. The MV is rated at seven amperes per positive plate for four hours, and the PV at six amperes for four hours; a sufficient number of plates are assembled in each cell to give the required capacity, and a sufficient number of cells are

connected in series to give the required voltage. Each cell consists of a rubber jar, an element and electrolyte. The rubber jar consists of a deep rectangular box of hard rubber, with walls one-eighth of an inch thick, more or less, according to the size and service. In the bottom of the jar, and made integral with it, are bridges or ribs of height consistent with the service, and whose function it is to support the weight of the element and to provide space, into which is deposited the sediment thrown off by the plates with wear.

Standard Capacity. Present practice is to rate batteries on the basis of their four-hour capacity; for instance, a nine-PV cell is rated at twenty-four amperes for four hours; the eleven-MV cell is rated at thirty-five amperes for four hours. The reason for this is that present practice is to so construct the vehicles that at an average current consumption they will run for about four hours. Exide batteries, with proper use, may be used from 15 to 25 per cent above their rated capacity.

Number of Cells. From forty to forty-two is the largest number of cells that it is customary to use, as more than this number cannot be charged in series from a 110-volt lighting circuit, and, without special and inconvenient apparatus. It is bad practice to charge batteries in parallel. In the smaller equipments, where the use of forty or forty-two cells would necessitate cells of very small size, it is common practice to use fewer cells of a larger size.

Rubber Covers. In pleasure vehicles service it is customary to enclose the cells with a tight-fitting rubber cover resting on the plate straps, slightly below the top of the jar, and to seal the joints with sealing compound, placing a rubber plug in a hole in the center of the cover for filling cells with water to replace evaporation, the plug being supplied with a small hole for the escape of gases. In commercial service, covers are often dispensed with altogether, as the batteries are usually in service a greater proportion of the time, and require filling and inspection much oftener. Where covers are used to prevent splashing, they usually rest on special supports and are seldom sealed.

Wood Separators. The separator, which has proved by experience to be the most successful, consists of a piece of wood with parallel grooves about one-quarter of an inch wide, spaced close together and plowed out on one side. The plain sides are placed directly against the face of the negative plates. A thin sheet of perforated rubber is placed against the grooved side of the wood and rests against the face of the positive plate. The wood is given a special treatment so as to remove any substances contained in it that would otherwise do damage to the plates.

Straps. The element consists of positive and negative plates burned to straps, and kept apart by separators interposed between the positive and negative plates. In assembling an element, a negative plate is laid down

with a separator on it, then a positive plate, separator, negative plate, and so on. The plates are so placed that all the lugs of the positive plates are on one side and all the lugs of the negative plates are on the other side. A strap, consisting of a flat strip of lead or lead alloy, having rectangular openings in it of the same dimensions

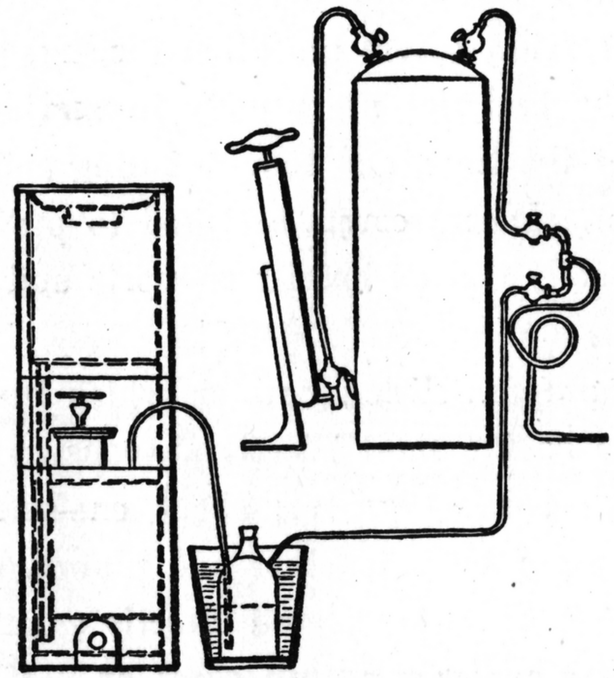

FIG. 20.—METHOD OF BURNING STRAP IN PLACE

as the cross-section of the lug of the plates, these openings being spaced to register with the lugs, is then placed over the plate lugs of the positive plates, and a similar strap is placed over the lugs of the negative plates. The lugs are then burned into integral union with the straps. In pleasure vehicle service it is customary to make the plate lugs comparatively short, so that the straps are somewhat below the top of the jar, and a cover consisting of

a rectangular piece of hard rubber is placed on top of the straps, which are furnished with projections extending through holes in the cover, and by which the cells are connected by burned joints. In commercial service the batteries are usually assembled with top straps, and the plate lugs extend above the top of the jar, the strap having

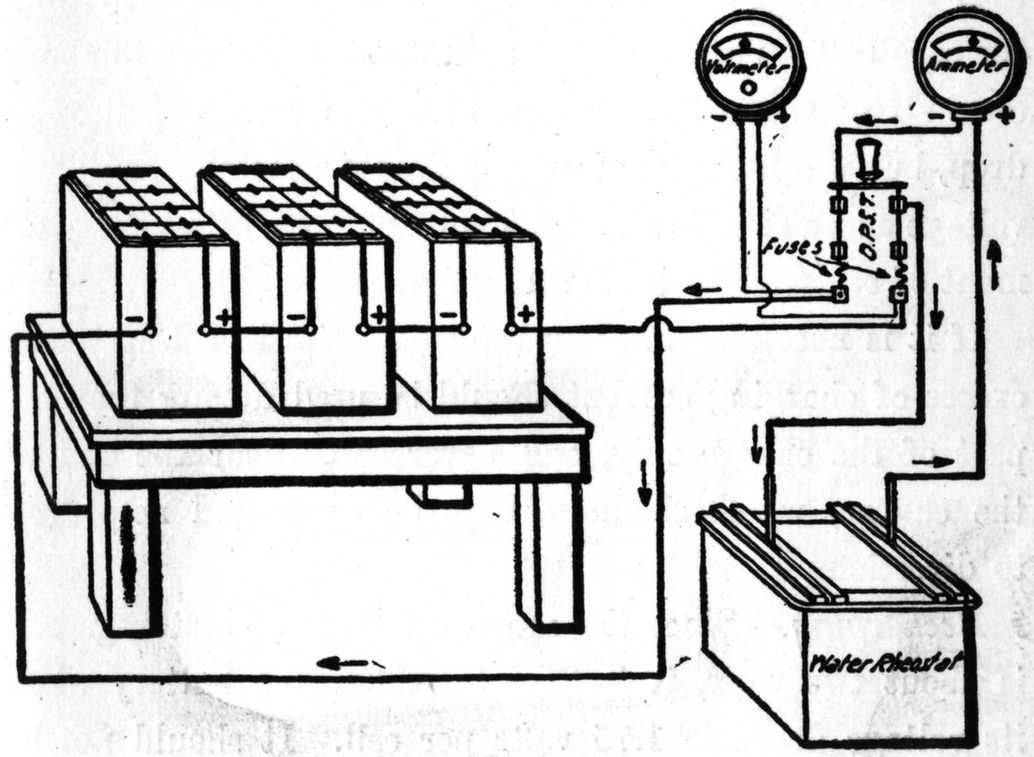

FIG. 21.—METHOD OF CHARGING STORAGE BATTERIES

two rows of holes in it, one row being placed over the corresponding row of plate lugs of one cell, and the other row of holes being placed over the plate lugs of opposite polarity in the adjoining cell, and the cell is completed by burning the lugs to the straps, which, in this case, themselves make the connection from cell to cell, an arrange-

ment for burning the battery straps in place being shown in Fig. 20.

Rate of Charging.—As a rule, the manufacturers of storage cells will give the rate at which a battery should be charged. This rate of current is maintained constant on the battery by means of a rheostat until the voltmeter shows that the voltage has risen until it averages about 2.5 volts for each cell. The current should then be reduced to about one-half of that original amount. The voltage will then drop, but the half-rate charging should continue until the voltage again rises to about 2.5 volts per cell. The arrangement of connections is shown in Fig. 21.

If it is necessary to charge the batteries in a hurry, the excess of charging current should be used during the first part of the charge only, and never at or near the end of the charge, which should always be conducted according to directions.

Recharging.—Since the average voltage of a storage cell is about two volts, it is time to recharge a battery when its voltage drops to 1.75 volts per cell. It should not be exhausted to a lower voltage than this, because the batteries will deteriorate very rapidly after the voltage falls below this amount. As a rule it is not advisable to recharge a battery unless its charge is at least one-half expended, and the length of charge given it, if only partially exhausted, should be proportioned to the fraction of the charge which is estimated to have been utilized. The charge in ampere-hours to be given a partially discharged

battery is often taken as the estimated ampere-hours of discharge, plus 15 or 20 per cent.

Temperature When Charging.—The temperature of the cells should be carefully watched during the charge, and if they become very hot to the touch the current may well be reduced, or the charge may be discontinued long enough to allow the cells to resume a safe temperature. Don't ever allow the temperature to rise above 100 degrees F.

How to Test Cells.—When testing cells, a low-reading volt-meter should be used to determine the voltage of each cell. The cell voltage should be taken when the battery is discharging. This may be done by connecting the battery to a rheostat. Any cells which register a low voltage should be marked for future attention. The low cell may be brought up to its proper voltage when the whole battery is recharged, but if it remains low after recharging, it shows that the cell is either short-circuited or plates have deteriorated.

The specific gravity of the cell is tested by means of a hydrometer. When fully charged, the cell should show a gravity of about 1.250 specific gravity, or 28 degrees Baume. If, when testing the charged cells, any one is found which has a smaller density, it will be found that for some reason it is not in the proper condition. The arrangement of batteries connected for test discharge is shown in Fig. 22.

Level of Liquid.—It is customary to keep the liquid within the cells at such a height as to fully cover the elements. If the level is reduced, spilling or bubbling, fresh

electrolyte of the proper gravity should be added to replace the loss. In case the loss has been occasioned by evaporation, the proper quantity of distilled water should be added.

Why Cells Are Short-Circuited.—Sediment which forms in a cell may be due to the active material scaling off the plates from the effects of hard service, jarring or an excessive rate of charge, and collecting in the bottom of the jars. If it collects in sufficient quantity it may bridge

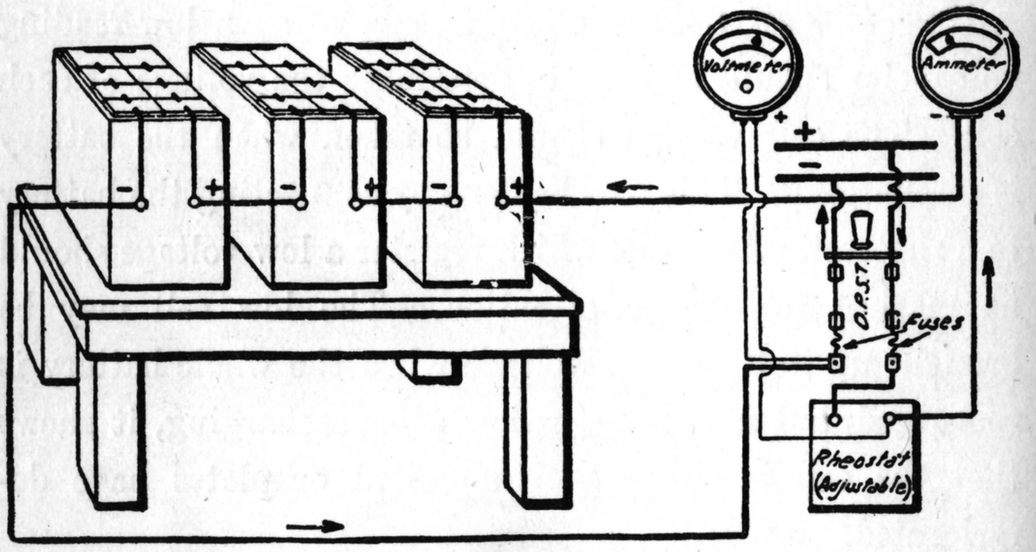

FIG. 22.—METHOD OF TESTING BATTERIES

the positive and negative groups of plates and short-circuit the cell, destructively discharging it. Sometimes the separators of the opposing groups of plates of a cell become bridged by sediment, and a short-circuit results. A short-circuited cell will generally head badly, and lose its voltage and charge rapidly. It is essential that sediment be removed from the jars, and the jars thoroughly washed out before much sediment collects. The plates should be exposed to the air as short a time as possible. In case a

cell appears to be internally short-circuited or otherwise defective, so that it cannot be brought up to a proper voltage, the cell should be replaced or given a special charge.

Sulphating.—When a battery is over-charged, or when it is allowed to discharge for any length of time, the plates will deteriorate. This effect is known as sulphating, because sulphate of lead is formed under these conditions. The effect of this sulphating is to prevent the cells from working properly. To prevent this condition, the batteries should never be allowed to fall below a certain voltage, and the battery of any car which is out of regular service should, at intervals of three or four weeks, be discharged through a rheostat, or otherwise, and then given a full fresh charge.

Preparing the Electrolyte.—The electrolyte or liquor for a storage battery, is a mixture of pure distilled water, and pure sulphuric acid; about five volumes of water to one volume of chemically pure sulphuric acid.

If the acid is not chemically pure it should be tested for hydrochloric acid, iron, and nitric acid. The acid should always be poured into the water, because if the water is poured into the acid an explosive ebullition may take place which would throw the acid about. The mixture will be hot at first. After it has cooled it should read 1180 to 1250 on the hydrometer. The mixture should be thoroughly cooled before it is poured into the cells. A lead lined vessel is the best for mixing the solution in.

STORAGE BATTERIES IN RAILWAY WORK

The storage battery plays an important part in modern railway practice, on both steam and electric lines. Especially is this the case on steam railroads, since the lighting of passenger cars by electricity has been almost univer-

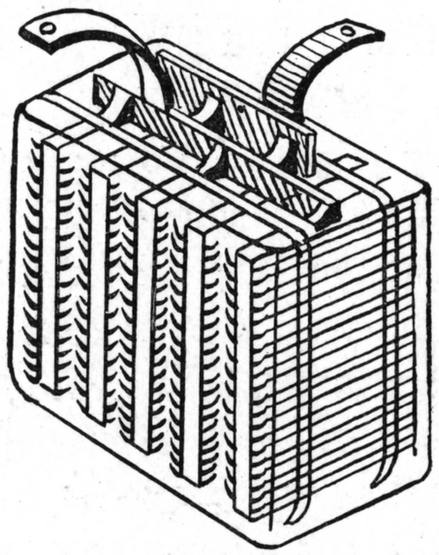

FIG. 23.—STORAGE CELL

sally adopted. While the train is in motion the small generator which supplies the current for the lamp is driven from the car axle, but when the train stops, the generator stops also, and the necessary current must be furnished from some other source, and the storage battery or accumulator is that source. This type of battery is also used in many cases to supply power to operate switches on electric locomotives, and motor cars, and also for operating block signal systems. In power houses, storage batteries

are used as a reserve supply of power, and act as a steadier of the load on the generators.

Figures 23, 24 and 25 show various forms of storage batteries intended for both stationary and portable service.

American Storage Battery.—The construction of this battery is illustrated in Figures 26 and 27. As shown in

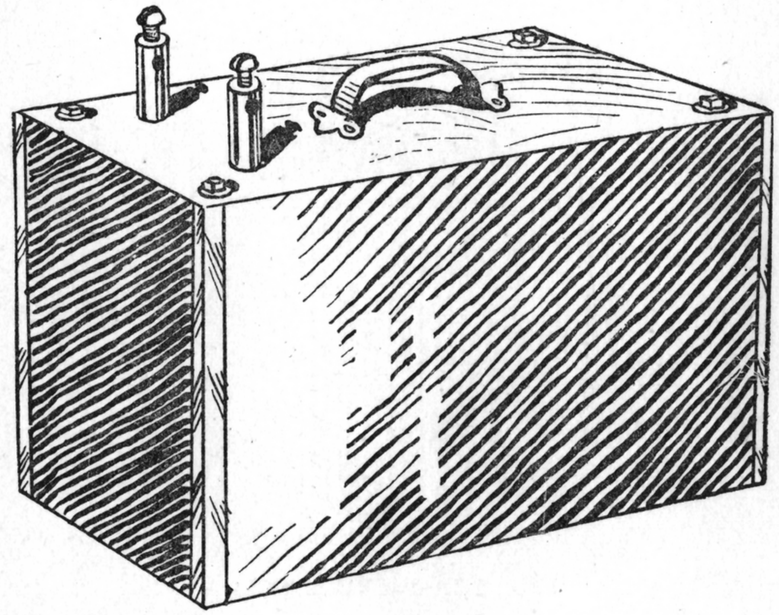

FIG. 24.—PORTABLE STORAGE CELL

Fig. 26 the lead plates are grooved in a horizontal direction, and the grooves incline upward. This is for the purpose of preventing the salts (peroxide) of lead formed on the plates from dropping to the bottom of the cell. Fig. 27 shows the plates ready to be placed in the cell. These plates are made of pure lead, and are insulated from each other, the insulating strips being notched at the ends, and three of them placed between each two plates, as shown in Fig. 27, the whole being held together by three strong

rubber bands which are stretched around the plates and lie in the notches cut on the ends of the insulating strips. Connection to the outside circuit is made by attaching the wires to the two bent strips shown at the top in Fig. 27.

Chloride Cell.—In storage batteries of this type the plates are in the form of lead grids, the small spaces or squares being filled with lead chloride mixed with zinc

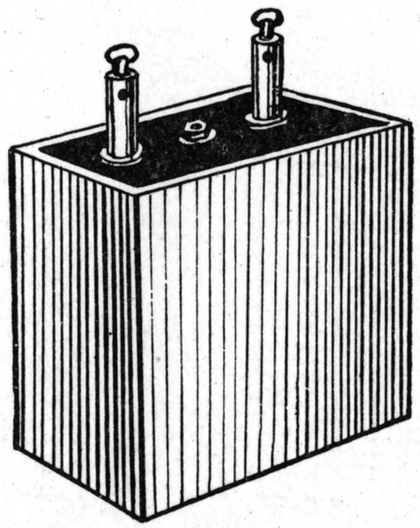

FIG. 25.—BICYCLE CELL

chloride, melted and then cast into small tablets about ¾ inch square and of the thickness of the negative plate which according to the size of the cell varies from ¼ inch to 5/16 inch. These tablets are then placed in molds, being held there by pins so that they clear each other about 0.2 inch and are at the same distance from the edges of the mold. Melted lead is then forced into the mold under 75 pounds pressure, completely filling the spaces between the tablets. This makes a solid lead grid holding small squares of active material, as shown in Fig. 28.

Edison Storage Battery.—The new Edison storage battery is known as type A. It is at present (1912) made in three sizes. A cell having four positive poles is termed A-4; a cell with six positive plates is termed A-6; and a cell having eight positive plates is called A-8. The following description and illustrations refer to cell A-4. Cells A-6, and A-8 are made in the same way as A-4, except that

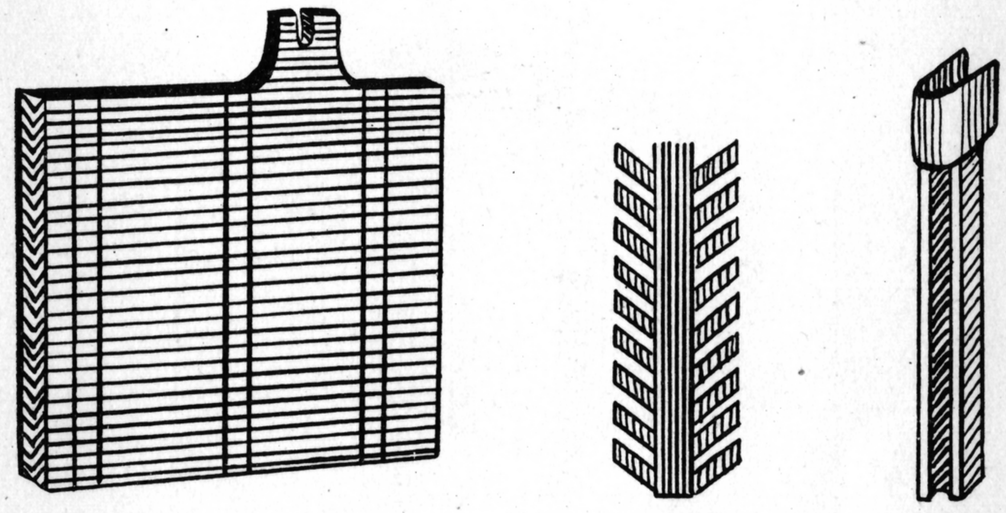

FIG. 26.—FRONT VIEW AND CROSS SECTION OF PLATE OF AMERICAN STORAGE BATTERY WITH SEPARATOR

they contain more plates, and consequently are larger. As before stated, each cell of the A-4 type contains four positive, and five negative plates. Each positive plate consists of a grid of nickel plated steel holding thirty tubes filled with the active material, in two rows of fifteen each, see Fig. 29. These tubes are made of very thin sheet steel, perforated and nickel plated. Each tube is reinforced and protected by small ferrules, eight in number, which prevent expansion, thereby retaining perfect internal con-

tact at all times. The active material, pulverized carbon, inside the tubes is interspersed with thin layers of pure metallic nickel in the form of leaves, or flakes.

This nickel flake is manufactured by an electro-chemical process.

A negative plate comprises in its make up twenty-four

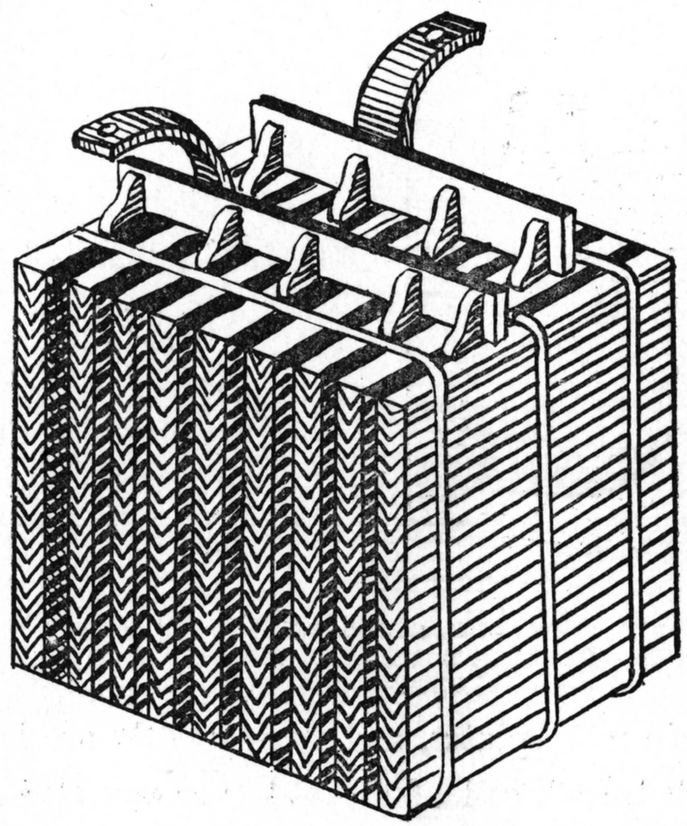

FIG. 27.—SET OF ELEMENTS OF AN AMERICAN STORAGE BATTERY CELL

flat rectangular pockets supported in three horizontal rows in a nickel plated steel grid.

The pockets are made of thin nickel plated steel, perforated with very small holes, each pocket being filled with an oxide of iron similar to what is usually called iron rust.

In the negative plate each pocket is subjected to very heavy pressure so that it becomes practically integral with the supporting grid. The can in which the plates are assembled is made of sheet steel, welded at the seams by the autogenous method, thereby making leakage, or breakage from severe vibration, practically impossible. The walls of the can, or container as it is sometimes called, are corrugated so as to give the greatest amount of strength with a minimum weight. The can is electro-plated with nickel, and a close union of the steel and nickel is attained by fusing the two metals together, making them practically one metal. The coating of nickel protects the steel from rust, and gives the cell an attractive appearance.

Fig. 30 shows the cell ready to be connected up. In a cell the positive and negative plates are assembled alternately, and connect, the positive plates with the positive pole, and the negative plates with the negative pole. The plates of each group are hung on a connecting rod perpendicular to, but integral with the pole.

They are correctly distanced on this rod by nickel plated spacing washers, and held firmly in contact by nuts screwed on both ends of the rod.

Fig. 31 shows the plates as they appear when assembled, before being placed in the containing can. Both the two outside plates are negative, and their outer surfaces are insulated from the walls of the can by hard rubber sheets, while specially designed hard rubber pieces are fixed between the can and the side and bottom edges of the plates.

These together with hard rubber rods inserted between the plates, maintain correct spacing of the plates at all points, and insure permanent insulation. These insulating strips, together with the bottom insulator, are shown in Fig. 32. The hard rubber insulating frames for the edges of the

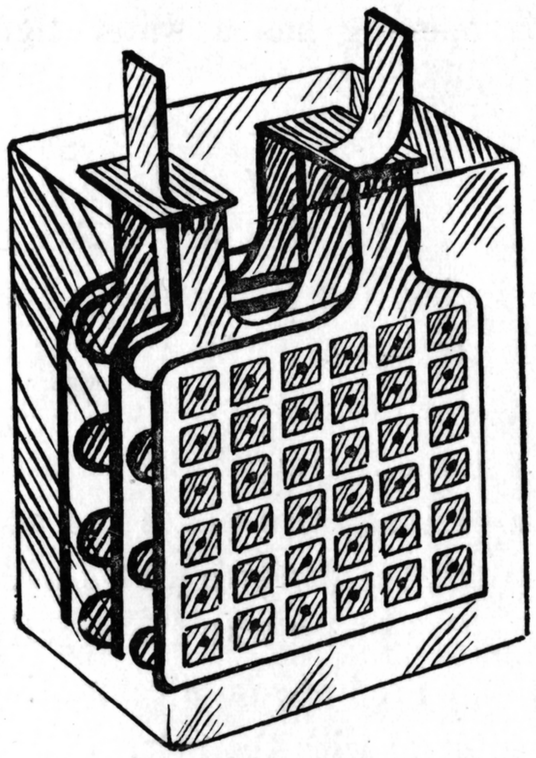

FIG. 28.—CHLORIDE ACCUMULATOR

plates appear in Fig. 31. Each cell has a cover which is welded in place by the same autogenous process used for the side and bottom seams of the can.

This cover, on which there are four mountings, is shown in Fig. 33.

Two of these mountings are the stuffing boxes through which the positive and negative poles extend. One of the other two is the "separator," so called because it sep-

arates spray from the escaping gas while the battery is charging. This prevents loss of electrolyte, and renders the gases inodorous. The fourth mounting is an opening for filling the cell with the electrolyte, and for adding distilled water to take the place of that which evaporates. This opening has a water tight cap held in place by a strong catch.

The electrolyte consists of a 21 per cent solution of caustic potash in distilled water. In order to keep the electrolyte in proper condition, only water need be added from time to time to replace that lost by evaporation.

The average discharge voltage is 1.2 volts. An A-8 type battery charged with the normal 420 ampere hour input will give an output of 300 ampere hours. When in service the solution should never be allowed to go below the top of the plates. The proper height of the solution is one-half inch above the top ends of the plates. It is best to always fill the cells with the solution, before charging, for the reason that in charging, the solution is raised to a false level. If the battery is in constant service, that is receiving a full charge each day, the electrolyte should be renewed once every eight or nine months, but when the battery is not used continuously a renewal once every year, or year and a half is ample.

Lead-zinc Storage Battery.—In this cell the positive plate is made of perforated lead sheets riveted together with lead rivets, and formed by the slow process of charging and reversal, which has already been described. The

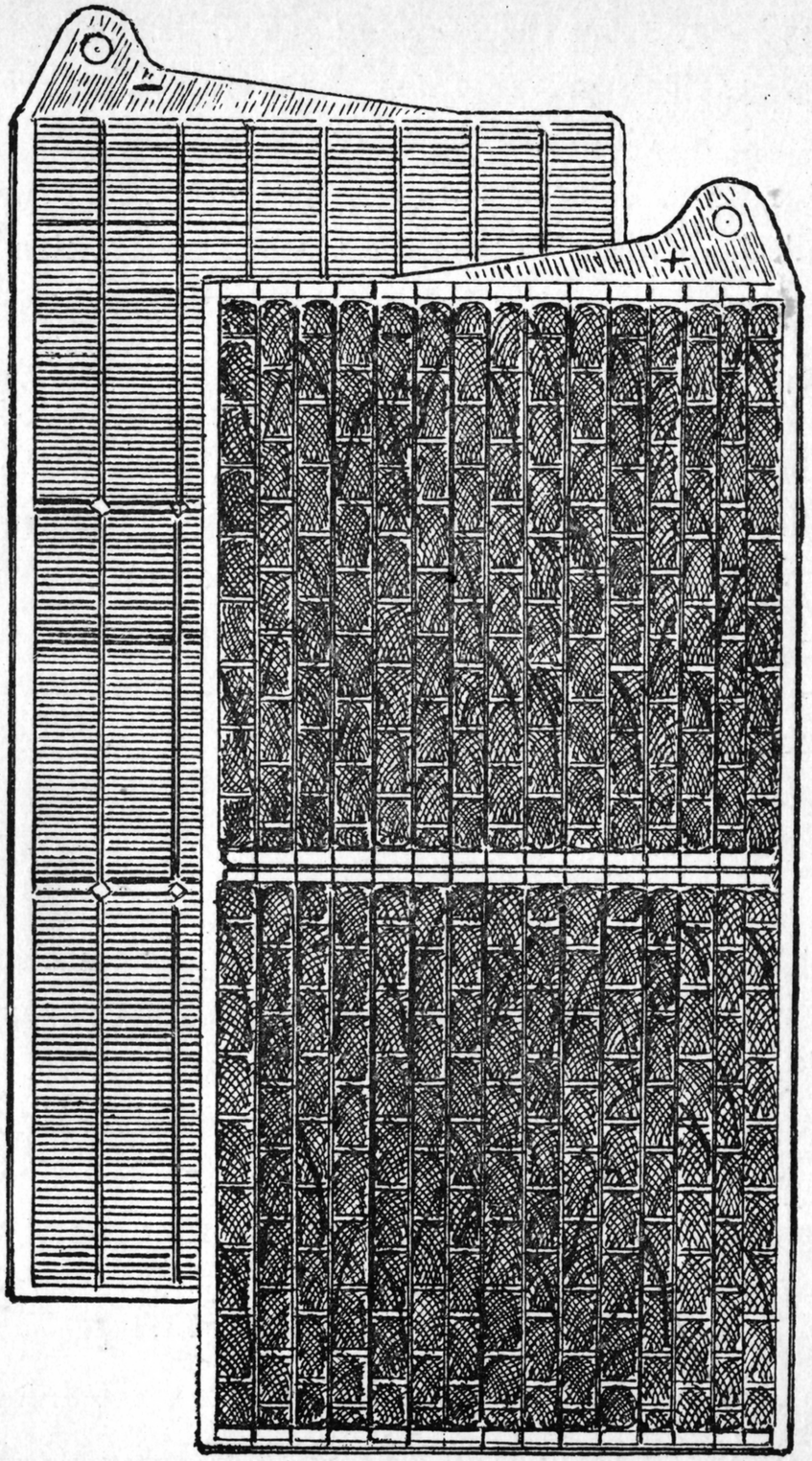

FIG. 29

negative element, or plate, is a zinc amalgam which swells up, or expands when it is charged.

This amalgam lies on the bottom of the jar, while the lead element is suspended above it. The voltage (E. M. F.) given by these cells is slightly higher than that given by the lead-lead cell, and they weigh less for the same capacity.

They are excellent for signal work, but for reserve power the lead-lead cell is to be preferred on account of its ability to withstand severe usage.

The cells are mounted in trays in manner shown in Fig. 34. These trays are of wood, having attached thereto metal cradles for holding the cells, and metal clamps on top for securing them in place.

The electrical connections between cells is then effected, the positive pole of one cell being connected to the negative pole of the next, and so on. These connections fit over the tapered poles or terminals of the cells, and are brought into intimate contact therewith by the nuts which screw on the ends of the poles. Therefore, to remove a cell from a tray, or to disconnect one cell from the other, it is only necessary to remove the nuts, and by means of a small jack, pull the connections off the pole.

Charging Storage Batteries.—This subject has already been discussed to some extent, (see page 74), but a few additional hints may not be out of place.

Storage batteries cannot be charged with alternating current. The current must in all cases be direct.

Should the only available source be an alternating cur-

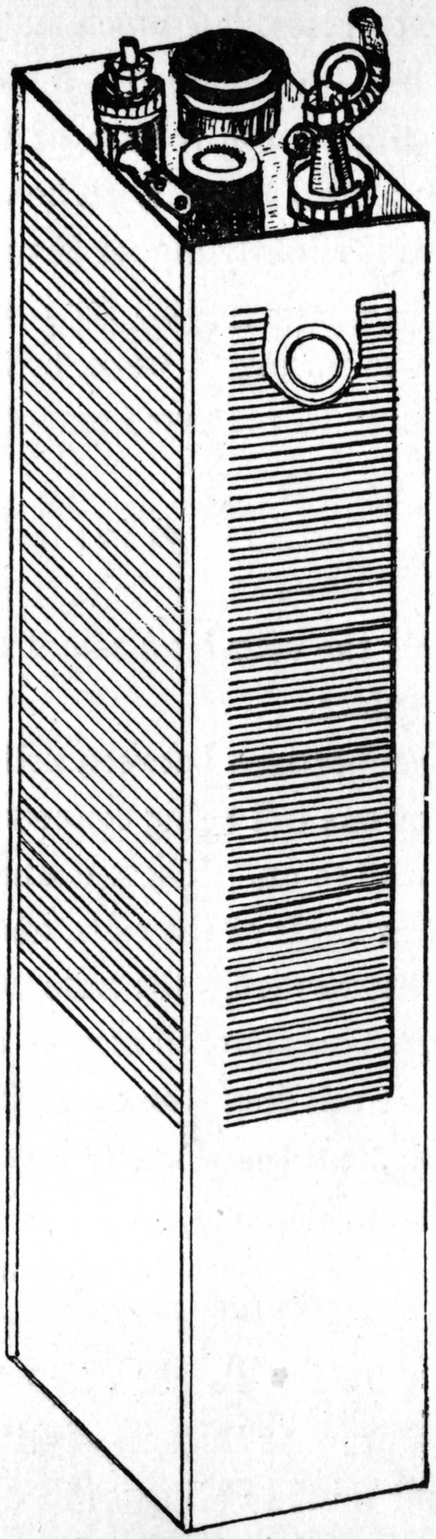

FIG. 30

rent circuit the conversion to direct current may readily be accomplished by means either of a mercury arc rectifier, or a motor generator set.

The following table shows the voltage necessary to charge various numbers of cells:

20	cells require line voltage of	37.	volts
24	cells require line voltage of	44.4	volts
28	cells require line voltage of	51.8	volts
32	cells require line voltage of	59.2	volts
36	cells require line voltage of	66.6	volts
40	cells require line voltage of	74.	volts
44	cells require line voltage of	81.4	volts
48	cells require line voltage of	88.8	volts
52	cells require line voltage of	96.2	volts
56	cells require line voltage of	103.6	volts
60	cells require line voltage of	111.	volts
64	cells require line voltage of	118.4	volts
68	cells require line voltage of	125.8	volts
72	cells require line voltage of	133.2	volts
76	cells require line voltage of	140.6	volts
80	cells require line voltage of	148.	volts

A battery should be charged according to the amount of work to be accomplished. A seven hour charge at the normal rate is arbitrarily chosen as normal, for the reason that a battery will retain good efficiency up to this point. This, however, is not fixed. The length of charge may be

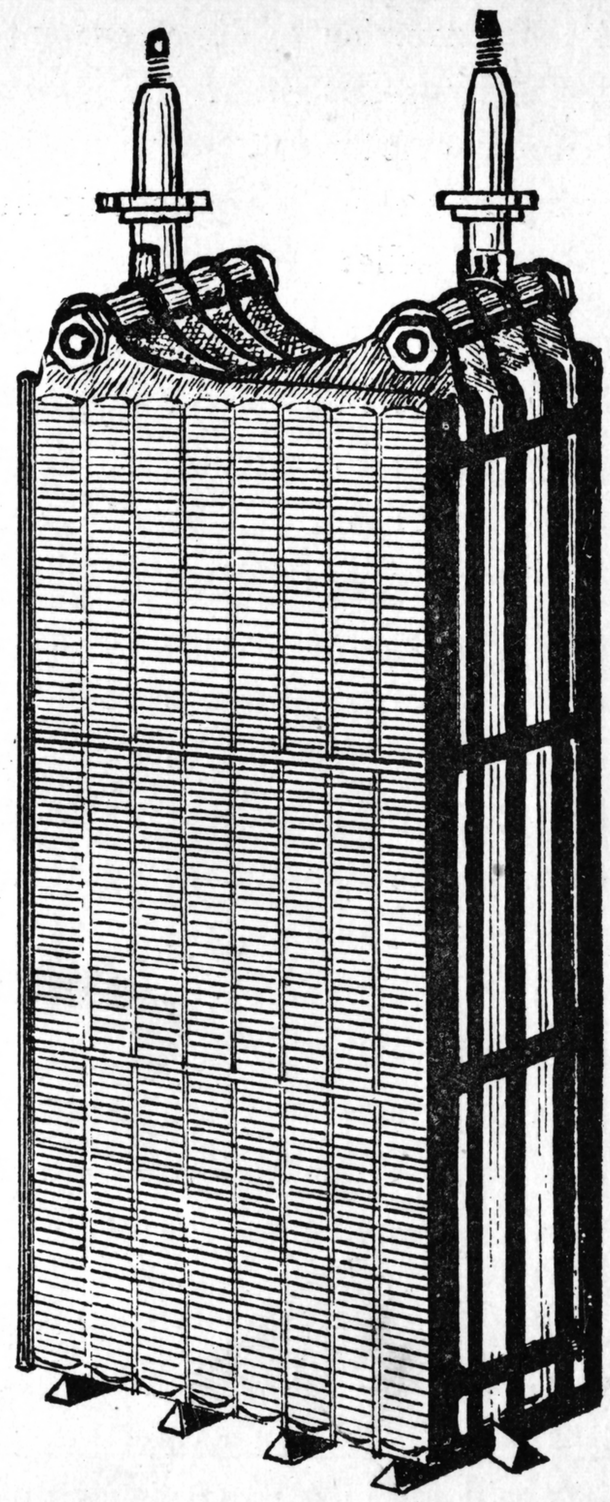

FIG. 31

varied at will, the highest practical output being reached on a ten-hour charge.

Overcharging, however, necessitates frequent filling of cells, and wastes current. Aside from this the result of over-charging is in no way harmful, provided the temperature rise is not excessive, it being advisable not to allow it to exceed 100° Fahr. at any time while charging.

While it is recommended in the case of the majority of storage batteries, that the charging current be reduced toward the close of the process of charging it has been found that in charging the Edison storage battery under ordinary circumstances it is not necessary to cut down or lower the rate as the charge progresses.

Charging may be done at double the normal rate for a one-hour boost, without injury to the battery.

The following table will show the normal rate of charge and discharge, also rated ampere-hour capacity and average discharge voltage of the various types of the Edison storage battery in its present form:

Type	Normal Charge Rate	Ampere Hour Input	Length Normal Charge	Discharge Rate	Rated Ampere Hour Output	Average Discharge Voltage
A-4	30	210	7 hours	30	150	1.2
A-6	45	315	7 hours	45	225	1.2
A-8	60	420	7 hours	60	300	1.2

Fig. 35 shows characteristic charge and, discharge curves of the A-6 type Edison storage cell.

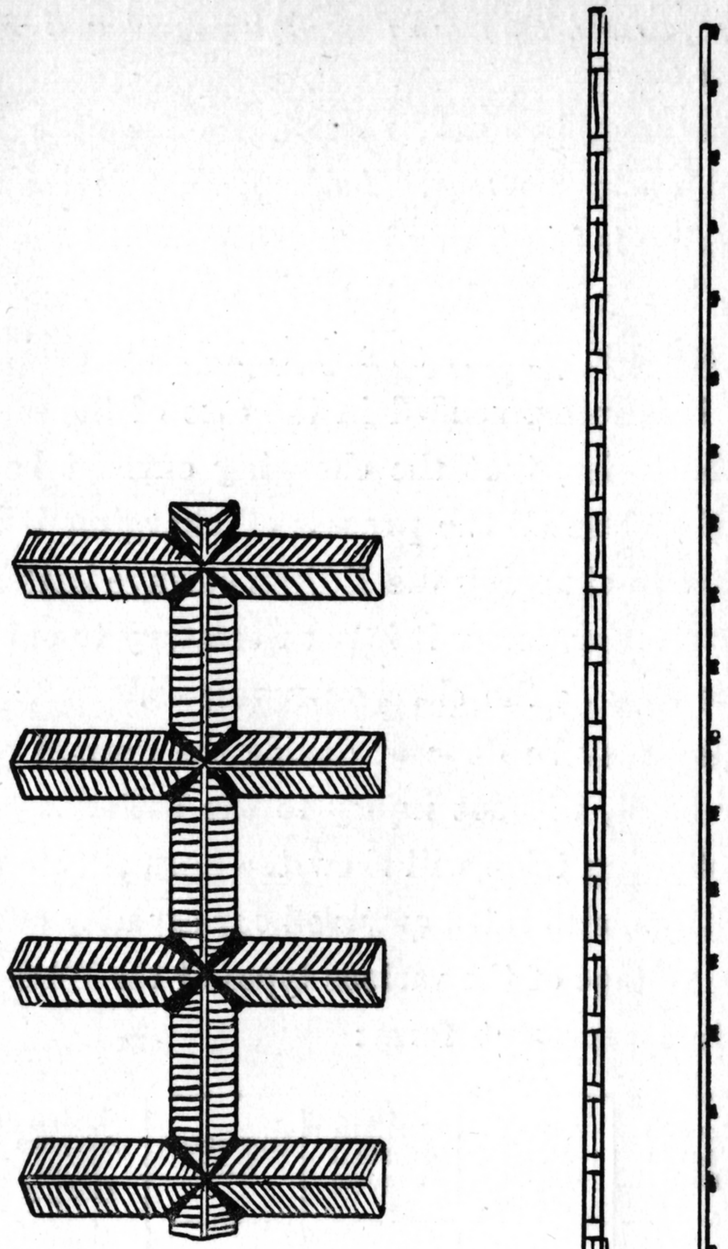

FIG. 32

*Storage Battery Charging in Railway Signal Work.**

There is a great diversity of practice in regard to the methods of charging storage batteries for railway and signal work. This is undoubtedly due to the fact that the installations are made over a very wide territory; that the

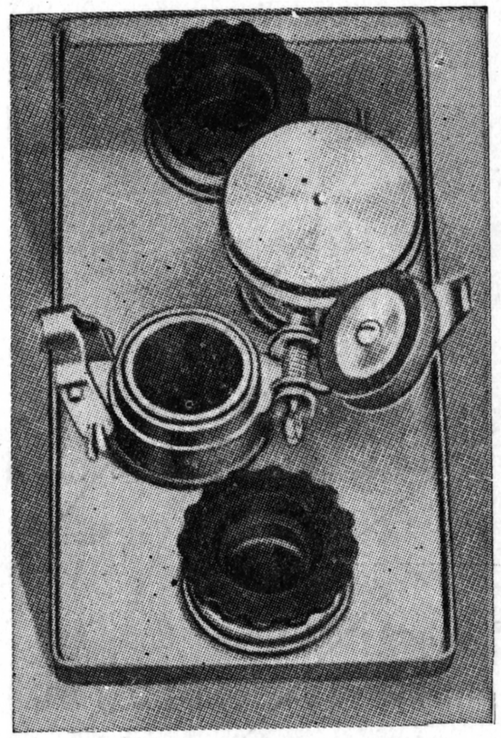

FIG. 33

engineers are more or less unacquainted with what the others are doing, and due to the lack of literature, or

*From a committee report presented at a meeting of the Railway Signal Association, Chicago, March 18, 1912, and published in the Railway and Engineering Review, March 19, 1912 issue.

precedence in regard to previous practice and experience. There are several general methods in use: the charging line system, the portable battery system, and the primary battery system are all in use by prominent railroads.

The charging line system is particularly adapted to a two or four-track line, where the length of the blocks is a minimum and traffic is more or less dense. Under these conditions charging approximately six to twelve miles on either side of a power house location, with a 600-volt d. c. supply, is found most satisfactory. This voltage admits of a fairly long section, and on the other hand is the practical limit consistent with the safety of men working on lines. In such cases the charging plants are so located that in case of a power plant failure the adjoining power stations on each side can charge through at a low rate and maintain the section in which the power plant has failed. An alternative system would be the installation of power houses at a maximum distance apart, with a portable set, or an emergency charging car held at a central station, that the same can be readily transferred and connected to a point where a power plant may have failed.

For portable batteries the arrangement for charging is very simple, it being only necessary to provide a charging apparatus which will economically provide the necessary range in order to charge the maximum and minimum number of batteries which will have to be charged at the same time.

This system is in very extensive use on single track roads or in territory where the traffic is not congested It has been the general practice in the past to provide portable batteries for the working of the signal mechanism and con-

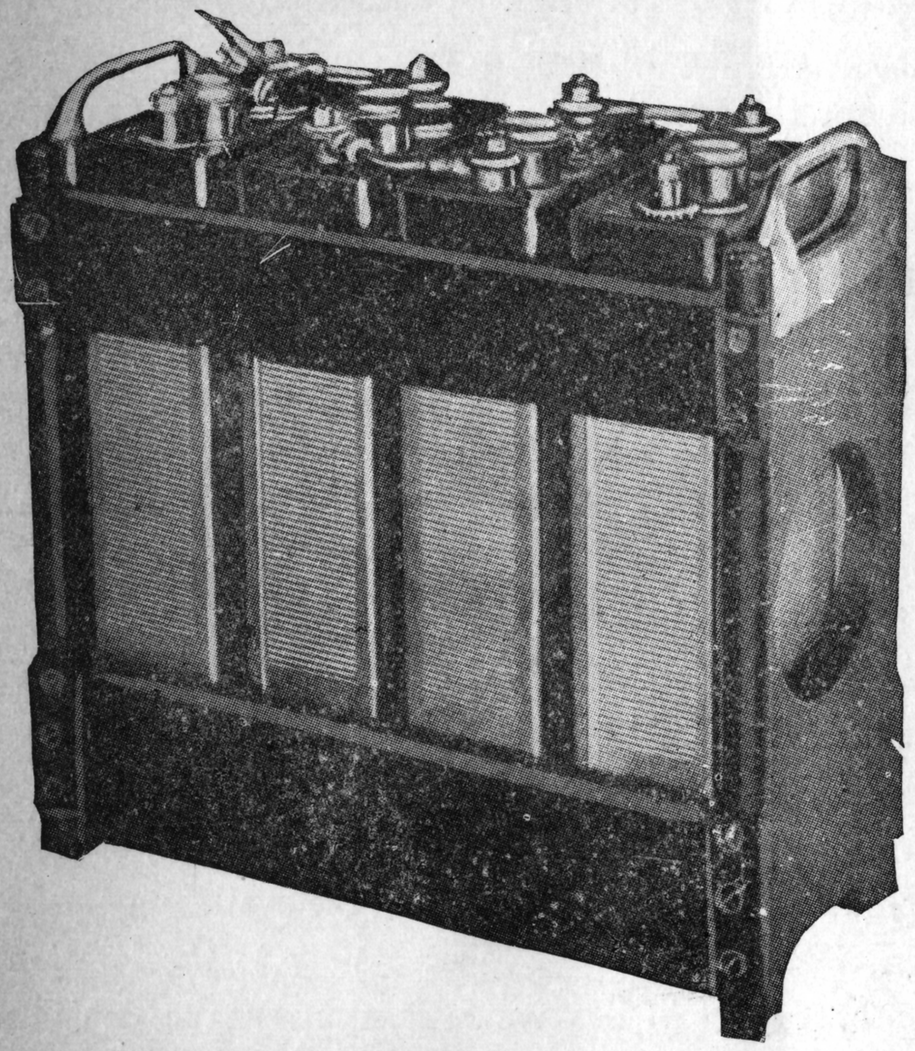

FIG. 34.—FOUR A-4 CELLS IN TRAY COMPLETE. ONE CELL HAS FILLER CAP OPEN TO SHOW CONSTRUCTION

trol circuits only, retaining the gravity track batteres in service. However, it would probably be economical to extend the system to the track circuit supply, also using the

necessary number of cells in multiple, so that the track batteries would require recharging at the same intervals as the signal batteries.

Gravity battery is also used to a certain extent for the charging of signal batteries. Under this system the storage batteries are floated, and a very positive energy is provided for the operation of the signals. This arrangement will, of course, require the frost-proof battery wells and a large amount of labor in renewing gravity batteries. The advisability of such a system, in comparison with the others, can be worked out on a dollars-and-cents basis, considering the interest cost on original investment, in comparison with the maintenance cost of the various systems, and a result be determined upon which is the most practicable for the local conditions.

Fig. 36 shows efficiency curves comparing two methods of charging as pursued by the signal department of various railways. In actual practice the question of a charging set generally resolves itself into a mercury arc rectifier, a motor generator set or a steam or gasoline engine set, as may be adapted to the local conditions, and the availability and cost of an electrical or steam power supply to the location of the proposed set in relation to fixed attendance which will permit their being operated without additional help. At points where a steam supply is accessible to a signal maintainer's headquarters, very satisfactory service can be obtained from a steam generating set. Such an arrangement is particularly adaptable to a pumping plant on the railroad.

At these points the generating plant can be operated by the pumpman without other additional expense to the railroad than the coal consumed. A number of such instal-

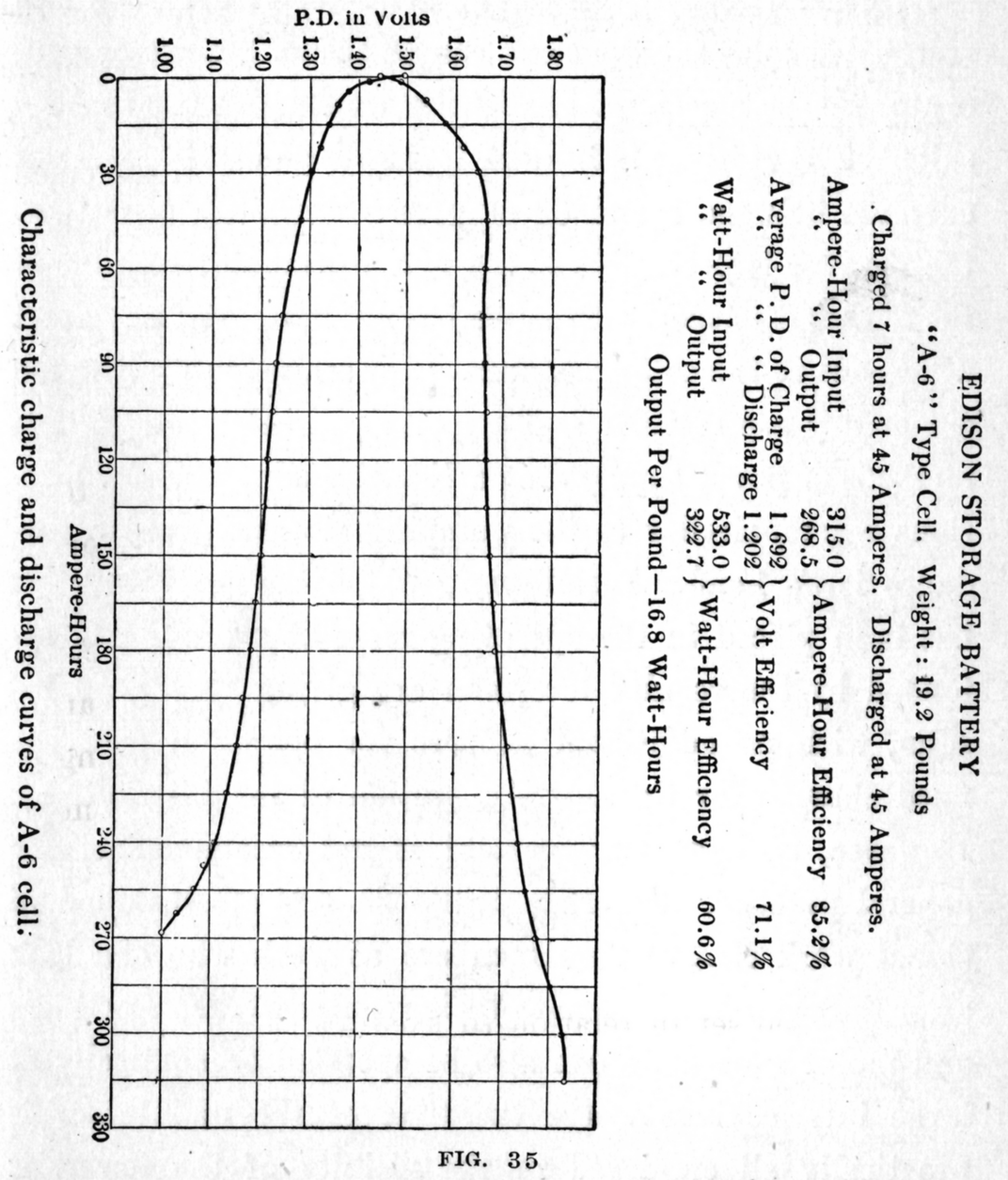

FIG. 35

lation are in service and are giving very satisfactory service. Of course, questions arise as to the proper distribution of

charges between the motive power and signal departments. However, there is no question in regard to the saving to the railroad.

At other points where electrical power is available and reasonable rates for the same can be secured, a motor generator set, or mercury arc rectifier would give the best results. The rectifier is limited to a voltage of 175, and for currents between 5 and 50 amperes. For such conditions the rectifier is preferable to the motor generator set, due to the higher efficiency. Practice has not developed any great difference in the cost of attendance or maintenance between a mercury arc rectifier and a motor generator set. These methods of power supply are particularly adaptable for locations where, similar to the pumping stations, fixed attendance is on hand. Installations where the generating set has been placed in the operating room of a tower and attended by the regular leverman are giving very good results, with no additional expense for operation over the fixed charges for the entire operation of the interlocking. However, such an arrangement is not recommended for general practice. At other points the sets are installed in signal work shops where men are at work who can look after the same in addition to their regular work. Rectifiers and motor generators can also be operated economically at large interlockings where the time of the maintainer is practically all employed in the vicinity of the tower, it being only necessary for him to make an occasional inspection of the apparatus.

Fig. 37 shows the relative floor space occupied by various charging outfits employed in this class of work.

A gasoline engine charging set requires more floor space, more attendance, a greater original cost and greater fuel cost than the arrangements suggested above, and, consequently, should not be installed until after a thorough investigation has been made of all other methods of charging. There are, however, a considerable number of these sets in service in railway signal work, and very satisfactory operation is secured from them.

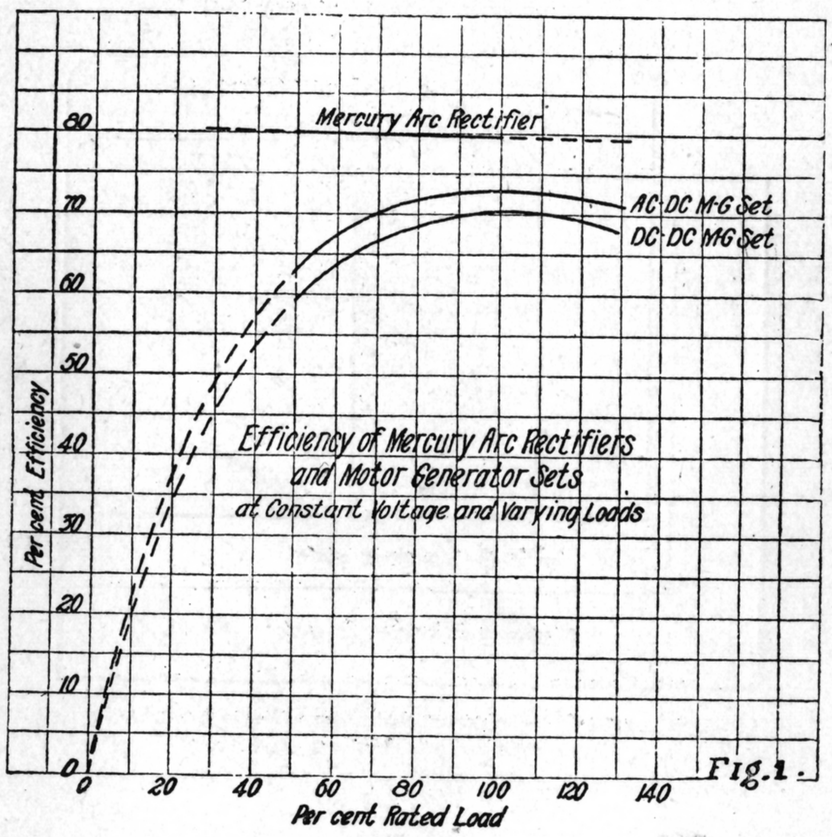

FIG. 36

In rare cases direct current can be obtained under proper

conditions for the charging of signal batteries. When this exists we have an ideal condition, as practically no attendance is required, and if the cost of power is reasonable, and the voltage such that a large fixed resistance does not have to be used, this system is better than any of the others

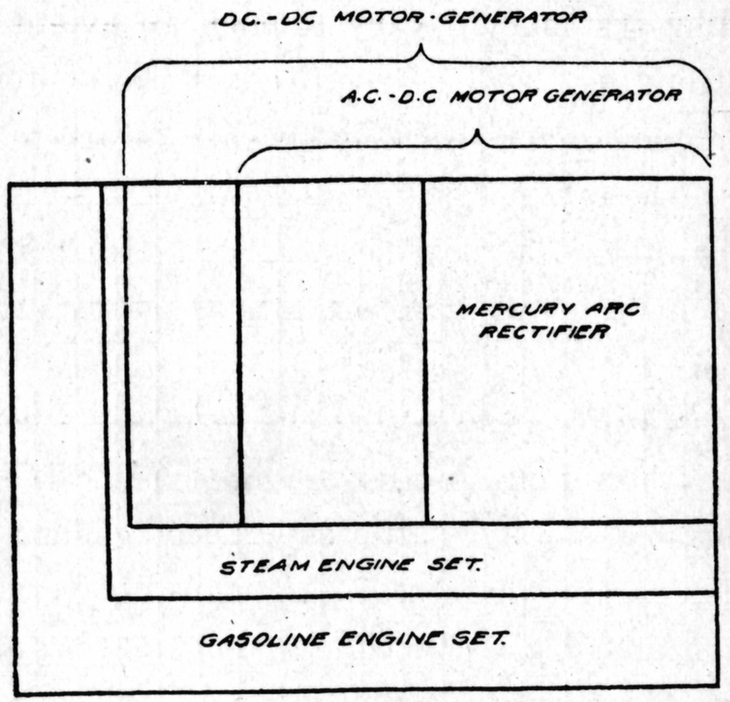
D.C.-D.C MOTOR-GENERATOR
A.C.-D.C MOTOR GENERATOR
MERCURY ARC RECTIFIER
STEAM ENGINE SET.
GASOLINE ENGINE SET.
RELATIVE FLOOR SPACE OCCUPIED BY 5 K.W. BATTERY CHARGING OUTFITS

FIG. 37

mentioned. It is, however, almost impossible to secure direct current under the necessary requirements.

It is considered that a grounded system, such as is used for trolley supply, can be properly used for the charging of storage batteries at an interlocking, or at a portable charging station where all connections are handled by a man who is, to a certain extent, experienced in the work

and to whom all the connections are readily visible or accessible. It is not, however, considered good practice to use a grounded system for charging line work, as the danger from loss of current, or injury from grounds is considered too great; and, in some cases, the voltage of the trolley system will vary to such an extent that constant attendance will be required at the switchboard.

Preliminary reports were received in regard to jelly electrolyte. These varied so greatly and were so inconsistent with each other that it is necessary that further investigations be made before a report can be offered to the association.

The committee desires that the association consider the following corrections in the present specification for lead type portable storage batteries. These changes are submitted in paragraph form, so as to readily permit of consideration and discussion before being incorporated in the language of the specification:

(a) The use of soft rubber edges on cell covers should be discontinued.

(b) The table of sizes and number of cells should be revised so that all the sizes will be based on the eight-hour discharge. This is necessary, so that all manufacturers will be in position to know the exact size of battery required, and so that our cells may be of a commercial rating that is a standard for most other types of cells.

(c) Cases should be made of well-seasoned hard wood, either maple, ash or oak.

(d) The wooden parts, instead of being painted with asphaltum, should be treated in boiling paraffin.

(e) The bevel on the inside of the top of the case should be eliminated.

(f) The supporting hard rubber rib in the bottom of the jar should be not less than three-sixteenths of an inch on the top.

(g) The rubber jars should be able to withstand a high voltage insulation test.

(h) The connections between the cell and terminal post in both types of cell shall be made with lead pipe.

(i) The maximum specific gravity should be given as 1.285 instead of 1.300 at 70 degrees Fahrenheit.

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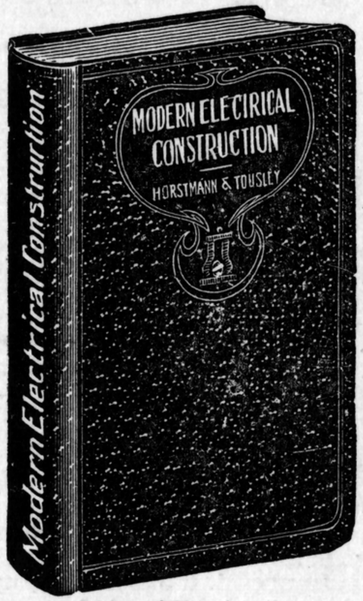

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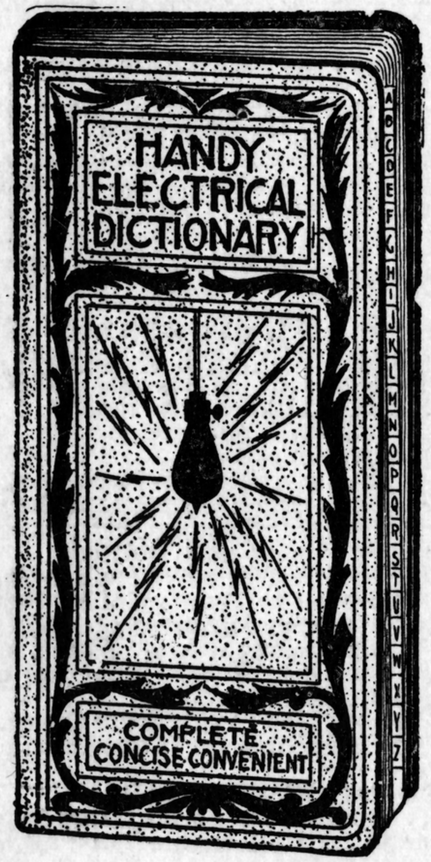

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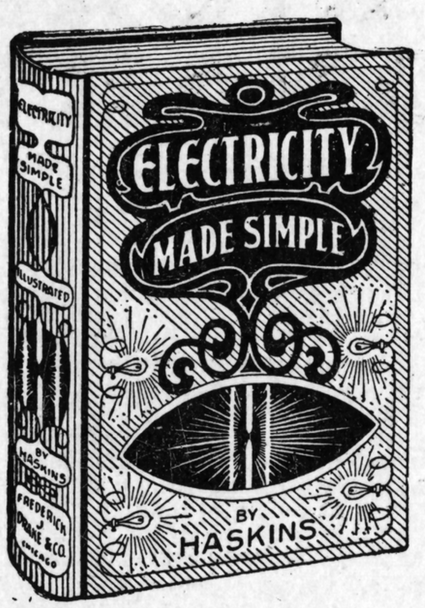

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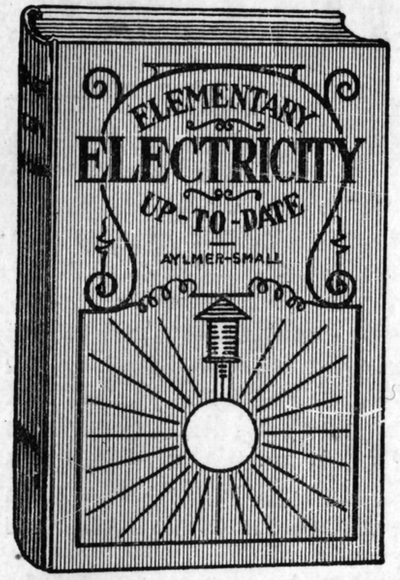

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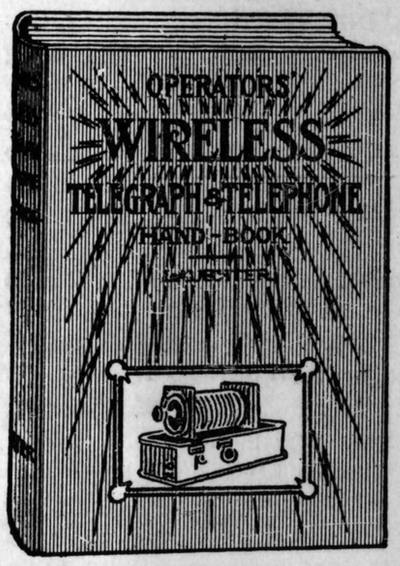

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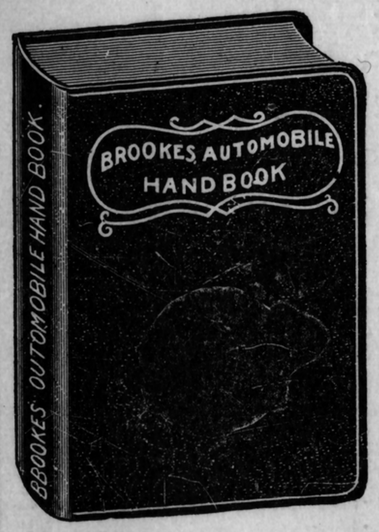

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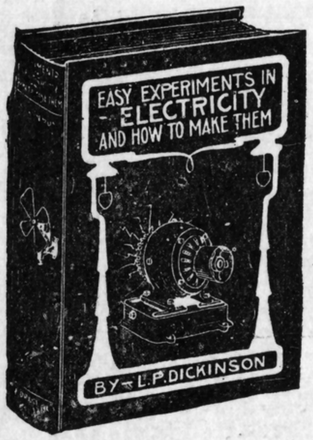

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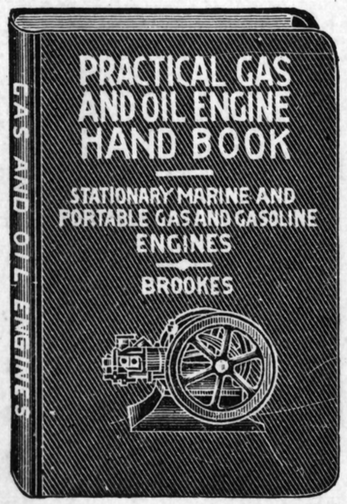
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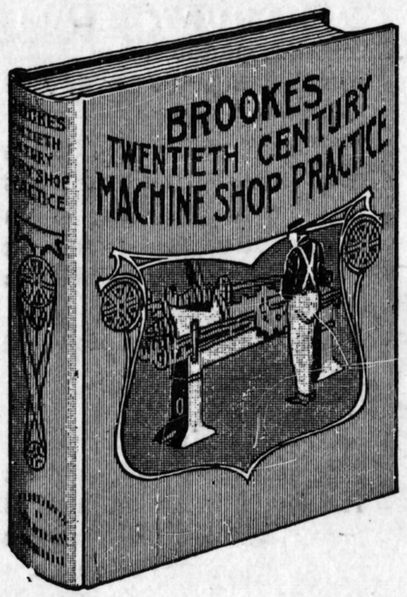

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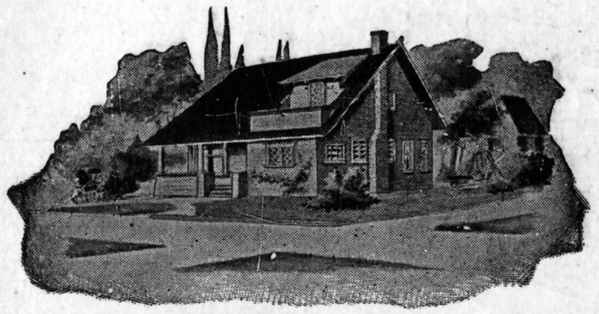

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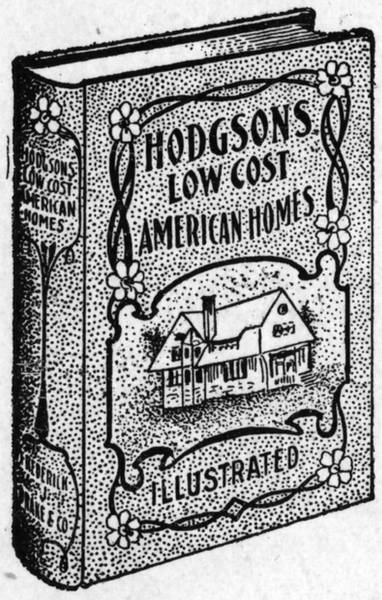

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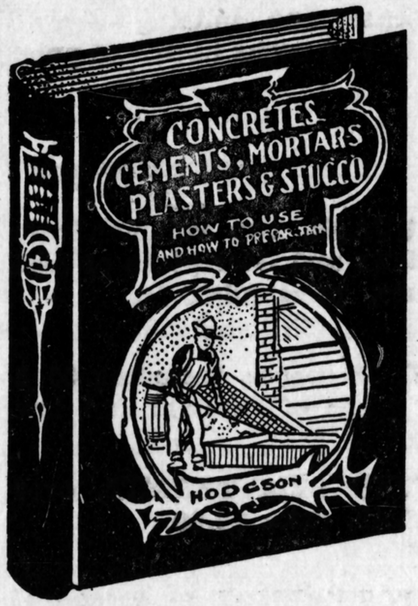

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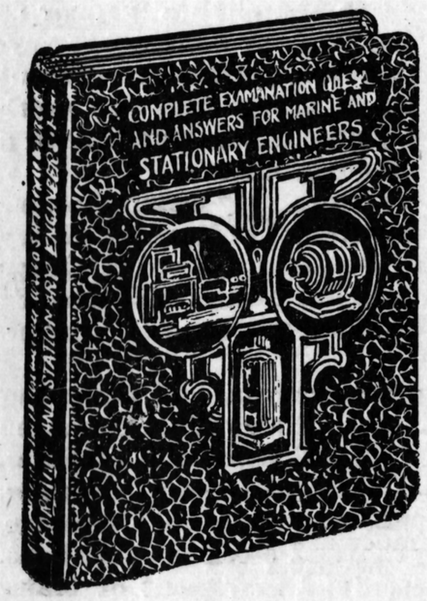

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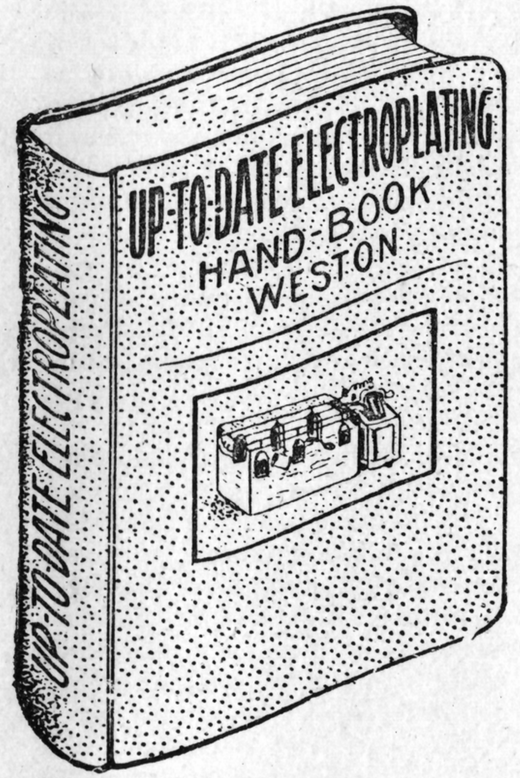

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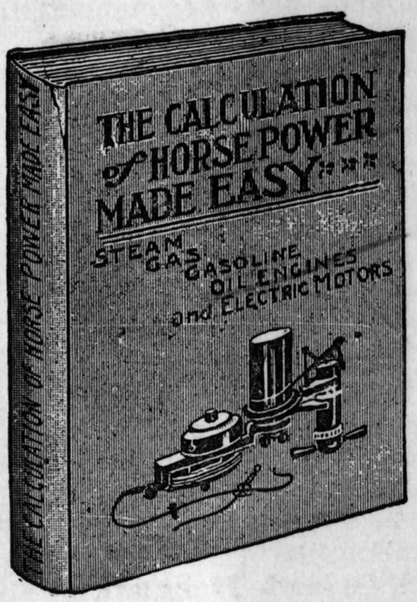

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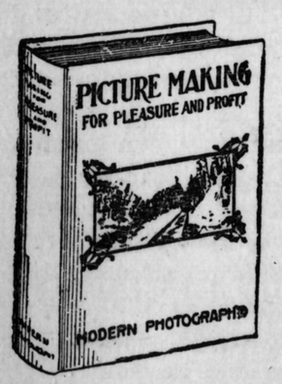

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